2007

The value of oil mallee plantations and revegetated farm land in the southern wheatbelt region of Western Australia for the conservation of the Western Pygmy Possum (Cercartetus concinnus)

Marie Short
Edith Cowan University

The Value of Oil Mallee Plantations and Revegetated Farm Land in the Southern Wheatbelt Region of Western Australia for the Conservation of the Western Pygmy Possum (*Cercartetus concinnus*).

By

Marie Short

A western pygmy possum (*Cercartetus concinnus*)

A thesis submitted in partial fulfilment of the requirements for the award of Bachelor of Science (Environmental Management) Honours

At the School of Natural Sciences
Faculty of Computing, Health and Science
Edith Cowan University
Joondalup

Supervisors:
Dr Eddie van Etten
Dr Patrick Smith
Dr Mark Lund

Date of Submission: 9th November, 2007

ABSTRACT

Revegetation has the potential to enhance conservation of wildlife in rural environments, but few studies have tested whether the proposed benefits are realized. It is important to understand the role played by farm tree plantations in the landscape and how the potential biodiversity benefits may be enhanced without interfering with economic goals (Lamb, 1998).

The adoption of oil mallee farming systems across the agricultural zone in south-west Western Australia is resulting in large areas of farmland being planted to native perennial tree species (Smith, 2004). While not planted for their conservation benefit, oil mallee systems may nonetheless enhance biodiversity. The Commonwealth Science and Industry Research Organisation (CSIRO) and the Cooperative Research Centre (CRC) for Plant Based Management of Salinity are funding a three year project within the Narrogin district of Western Australia to determine the biodiversity values of oil mallee farming systems (Smith, 2004). The surveys examine the diversity and abundance of native animals in the oil mallees and other vegetation types on 30 farms, using 108 sites in the Narrogin region of the West Australian wheat belt. Results from the first survey in 2005 showed that a wide variety of native animals can be found in the oil mallee plantations such as birds, mammals, reptiles, amphibians and invertebrates. Therefore it appears that these plantations are providing some resource to native biodiversity (Smith, 2004).

One mammal species that had been observed throughout the project surveys and particularly within oil mallee plantations was the western pygmy possum (*Cercartetus concinnus*). *C. concinnus* is a small nocturnal marsupial that is fawn or reddish-brown above and white below with a finely-scaled, naked tail. Adult western pygmy possums weigh 8-20 g (average 13 g) and have a head/body length of 71-106 mm and a tail length of 71-96 mm (Smith, 1995). Their diet consists of nectar, pollen, insects and other small arthropods and may also include small lizards (Bennett & Lumsden, 1995).

Little is known about many aspects of the ecology of western pygmy possums. The lack of information about this species may be due to their small size, cryptic nature and low trapability, as the nocturnal habits and mobility of these possums have made them difficult species for field study (Bowen & Goldingay, 2000). Effective management and

conservation of arboreal marsupials requires detailed knowledge of their habitat requirements (Kemp & Carthew, 2004). However, there have been few targeted studies on the western pygmy possum and there is clearly a need for further research on this small, cryptic species.

The utilisation of farm tree plantations by the western pygmy possum was an unexpected discovery and therefore, this study attempted to determine the habitat utilisation patterns of the western pygmy possum and the value of oil mallee plantations and revegetated farm land in the southern wheatbelt region. All of the study sites were situated on farms throughout the Shires of Narrogin, Cuballing and Wickepin. Based on observations from radio tracking, some particular habitat characteristics that seemed important to western pygmy possums became evident. These important habitat characteristics appeared to be the type of vegetation, whether large trees with hollows were in the vicinity and the amount of flowering trees available. It is hoped that this study can improve the low public-profile of the western pygmy possum to ensure continued support for conservation and management initiatives and; recommendations can be given to local farmers on how to manage and/or modify farm tree plantations to enhance their biodiversity value within the landscape.

USE OF THESIS

The Use of Thesis statement is not included in this version of the thesis.

COPYRIGHT AND ACCESS DECLARATION

I certify that this thesis does not, to the best of my knowledge and belief:

(i) incorporate without acknowledgement any material previously submitted for a degree or diploma in any institution of higher education;

(ii) contain any material previously published or written by another person except where due reference is made in the text; or

(iii) contain any defamatory material.

I also grant permission for the Library at Edith Cowan University to make duplicate copies of my thesis as required.

Signed [redacted]

Dated 14/02/08

ACKNOWLEDGEMENTS

Thank you to my supervisor Dr Eddie van Etten for your guidance during the year and your willingness to still be my supervisor from overseas, it was much appreciated. Thank you to Dr Mark Lund for becoming my supervisor during the second half of the year while Eddie was away and for providing assistance to me.

Thank you to CSIRO Sustainable Ecosystems in Perth for providing data from your Biodiversity Value of Oil Mallee Farming Systems project. In particular I would like to thank my supervisor, Dr Patrick Smith for providing the data and assisting with the data analysis. Thank you also to Steven Zabar for your assistance in the field, for helping with volunteers and providing recommendations and support. Thanks to other CSIRO employees; Dr Roger Lawes and Trevor Parker for your help during the year.

Thanks to the Centre for Ecosystem Management, ECU and CSIRO for providing financial assistance for this project.

Thanks to my fellow honours students, Sharyn Burgess and Christopher Doropoulos for the kindness you have shown me throughout the year. Thanks also to Tonja Boyd for providing editing advice.

A special thank you to my Dad, Mum, Sister and Mark for your love, prayers, support and encouragement that has been such a blessing throughout the year. Dad: thank you for always being enthusiastic and willing to help check the pitfall traps and assist with radio tracking during the night. Mum: thank you for your encouraging ideas and helping to check the pitfall traps and set up additional ones. Thanks Mum and Dad for putting up with me while I stayed at home during my field work, you're the best! Amanda: thanks for living with me this year and listening to my dramas! Mark: thank you for always showing a genuine interest in my project, for being a constant support and for helping me throughout the year.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

CHAPTER 1: INTRODUCTION

1.1 INTRODUCTION

1.1.1 Clearing and Revegetating

It is estimated that only 7% of the pre-European vegetation in the wheatbelt region of Western Australia has been retained (ABS, 2006). Protection and management of existing natural vegetation is a critical first step, but will not be enough on its own to arrest ecological degradation and ensure long-term sustainability of natural resources. Vegetation cover needs to be increased in many landscapes in Australia, either through natural regeneration or strategic replanting programs (Kimber *et al*, 1999).

Planting trees has become a major component of a farmer's annual program throughout Australia, particularly in Victoria and Western Australia. Farmers and graziers appreciate how trees can benefit their properties by providing shade and shelter to stock and crops, control of soil salinity, emergency fodder, improvements of farm aesthetics, an alternative source of income, and a host of other benefits (Heinjus, 1992). A survey conducted by the Australian Bureau of Agricultural and Resource Economics in 1994 on 2000 farmers across Australia, found that more than 25% of farmers recognised that revegetation also has benefits for nature conservation but little is undertaken directly for this purpose (Wilson *et al*, 1994).

The most common type of revegetation is the planting of native species in linear strips, including shelterbelts, tree rows and corridors (Brandenburg & Majer, 1995). To date, most revegetation in rural Australia has been motivated by issues related to agricultural productivity and land rehabilitation. However, vegetation established to meet these goals (including plant species used, spacing, size and shape of planting), will not necessarily create high quality habitat for flora and fauna. Shelterbelts in farmland for example, are designed to be effective at modifying wind flow and providing shelter, but the vegetation structure required for this purpose differs substantially from that found in native forest or woodland habitats. Consequently, while a shelterbelt provides habitat for some species, this is usually a secondary benefit that may be entirely incidental (Bennett *et al*, 2000).

In May 2002, the Land Management and Salinity Survey was conducted which found that 776 000 ha of trees had been planted for salinity management across Australia (ABS, 2003). The south west agricultural zone in Western Australia is considered the worst salt-affected area in Australia with widespread clearing of forests and native vegetation for agricultural purposes having contributed to extensive dryland salinity (ABS, 2006; National Land & Water Resources Audit, 2001). When native vegetation is removed, most of the rain percolates through the soil, causing the water table to rise. When the watertable reaches close to the soil surface, water is evaporated, leaving salts behind and causing land salinisation. Revegetation is a key strategy to reduce watertables and hence, salinisation. However for revegetation to have a more effective role in the protection of biodiversity across Australia, farm tree plantation practices that specifically incorporate defined conservation objectives need to be adopted (Sattler & Creighton, 2002).

1.1.2 Revegetation for Nature Conservation

Revegetation has the potential to enhance conservation of wildlife in rural environments, but few studies have tested whether the proposed benefits are realized. Published information is sparse and largely restricted to the use of revegetated areas by birds (Saab, 1999; Ryan, 2000; Barrett & Davidson, 2000). This lack of basic monitoring and research is a critical gap in our knowledge, particularly given that revegetation activities are widespread in Australia. They are supported by highly funded national environmental programs (e.g. National Heritage Trust [NHT] and the National Action Plan for Salinity and Water Quality [NAPSWQ]) and are promoted as having substantial benefits for biodiversity conservation (Kimber *et al*, 1999). It is critical to understand the role played by farm tree plantations in the landscape and how the potential biodiversity benefits may be enhanced without interfering with economic goals (Lamb, 1998).

Over the years there has been considerable debate about plantation forestry and its contribution to biodiversity (Norton, 1998). Some see plantation forestry as a threat to biodiversity without any positive values and others believe it does not need to be in conflict. Goals in plantation forest management should be to integrate productive and protective uses in the same landscape rather than replacing one with the other (Norton, 1998). In situations where revegetation is driven by specific objectives, such as tree planting for timber products, growth of fodder crops, provision of stock shelter, or establishing perennial vegetation in highly saline conditions, the design of the revegetation may be strongly determined by these objectives. However, with such constraints there may be opportunities for minor changes to design and management that will enhance wildlife conservation. Habitat values may be enhanced by modification of the size, shape or location of the plantation. For instance, location of tree plantings at a landscape scale could optimise connectivity between existing bushland remnants whilst not jeopardising their original purpose, such as recharge control or productivity enhancement. There may also be opportunities to increase the diversity of habitat structure and habitat resources for the fauna by adding local understorey species between some tree rows (Bennett *et al*, 2000). Regardless of the primary purpose of planting trees, they may also give secondary benefits (Heinjus, 1992).

A study conducted by Hobbs *et al* (2003), examined the faunal use of *Eucalyptus globulus* plantations in southern Western Australia. The study recorded species of amphibians, reptiles, birds, bats and ground-dwelling mammals such as the western grey kangaroo, inhabiting areas of eucalypt plantations. In general, faunal use of plantations was less than adjacent remnant vegetation, but more than open pasture. Hobbs *et al* (2003) stated that the inclusion of more species or a more diverse structure in the plantations may increase their use by fauna, but would also increase the management costs. However, there may be ways to increase diversity and structure which will have less impact on plantation management. For instance, understorey shrubs could be planted round the edges of the plantation, or blocks of understorey and other non-commercial species could be interspersed with the commercial blocks. The study indicated that current plantation management does provide limited biodiversity benefits (Hobbs *et al*, 2003). The extent to which biodiversity versus commercial benefits are enhanced will depend on an improved ability to maximise both (Hobbs *et al*, 2003).

1.1.3 Oil Mallee Plantations

The adoption of oil mallee farming systems across the agricultural zone in south-west Western Australia is resulting in large areas of farmland being planted to native perennial tree species (Smith, 2004). Mallee is the common name given to a plant which has many woody stems shooting from a lignotuber. During fire or harvest, the above ground mallee stems are lost, but the starch rich lignotuber remains intact underground. The mallee is able to sprout back from buds on the surface of the lignotuber, enabling the tree to survive (OMC, 2001). Beginning with Aboriginal people who used eucalyptus oil for medicinal purposes, eucalypts have a long history as beneficial plants. Australian export of eucalypt oil began to decline in the 1940s due to cheap labour and the establishment of Tasmanian Blue Gum timber plantations in developing countries. Currently, Australia imports eucalyptus oil despite the abundant domestic supply of eucalypt species.

Allan Barton, a professor of chemistry at Murdoch University, Western Australia, became aware of the eucalyptus oil trade situation in 1980. Barton experimented with various cultivars and growing techniques to determine the feasibility of a new eucalyptus oil industry for Western Australia, which is now known as the Oil Mallee Project (Barton, 2000). Today more than 42,000 ha and 17 million oil mallee trees have been planted, providing a solid supply base for an industry that could become a major economic underpinning of large rural regions in the future (Barton, 2001). Oil mallee products fall into two categories, those that come from the oil in the leaves and those that are derived from the woody biomass. The woody biomass produced during harvesting can be used as a high-grade activated carbon, which has uses in gold processing and water treatment. Cineole, the primary active ingredient which gives eucalypts their distinct aroma, has a number of uses such as an ingredient in pesticides, pain relief products and flavouring (Barton, 2000).

While not planted for their conservation benefit, oil mallee systems may nonetheless enhance biodiversity. The Commonwealth Science and Industry Research Organisation (CSIRO) and the Cooperative Research Centre (CRC) for Plant Based Management of Salinity are funding a three year project within the Narrogin district of Western Australia to determine the biodiversity values of oil mallee farming systems (Smith, 2004). The Biodiversity Value of Oil Mallee Farming Systems project led by Dr Patrick Smith from CSIRO Sustainable Ecosystems in Perth Western Australia aims to determine whether oil mallee plantations on farms provide additional habitat for native animals, and if so how they compare to other types of natural and planted vegetation in the landscape. The final survey to examine the diversity and abundance of native animals in the oil mallees and other vegetation types on 30 farms, using 108 sites in the Narrogin region of the Western Australian wheatbelt was due to be completed in September 2007. Results from the first survey in 2005 showed that a wide variety of native animals can be found in the oil mallee plantations such as birds, mammals, reptiles, amphibians and invertebrates. Therefore it appears that these plantations are providing some resources to native biodiversity (Smith, 2004). One mammal species that has been observed throughout the project surveys and particularly within oil mallee plantations is the western pygmy possum (*Cercartetus concinnus*) (Plate 1.1).

Plate 1.1: A western pygmy possum (*Cercartetus concinnus*).

1.2 PYGMY POSSUMS (Burramyidae)

C. concinnus belongs to the marsupial family Burramyidae which is comprised of 5 extant species of pygmy-possum in Australia and New Guinea (Tulloch, 2006). The family Burramyidae includes the mountain pygmy possum *Burramys parvus*, little pygmy possum *Cercartetus lepidus*, eastern pygmy possum *Cercartetus nanus* and two subspecies of the long-tailed pygmy possum *Cercartetus caudatus: C.c. macrurus* (Australia) and *C.c. caudatus* (New Guinea) (Osborne & Christidis, 2002).

The distribution of *Cercartetus concinnus* (western pygmy possum) extends from the south-west of Western Australia and coastal South Australia (including Kangaroo Island) to north-western Victoria and adjoining areas in New South Wales (NSW) in areas with high temperatures and low rainfall (Bennett & Lumsden, 1995) (Figure 1.1). The western pygmy possum has a relatively wide but disjunct distribution across western and southern Australia and is listed as common across its range, except in NSW where it is endangered (NSW NPWS, 2001). The western pygmy possum is generally found in heathlands, shrublands and dry forests with a heathy understorey. The understorey characteristically includes a range of myrtaceous and proteaceous shrubs (such as banksias, grevilleas, callistemons, hakeas and melaleucas) (Misso, 1997).

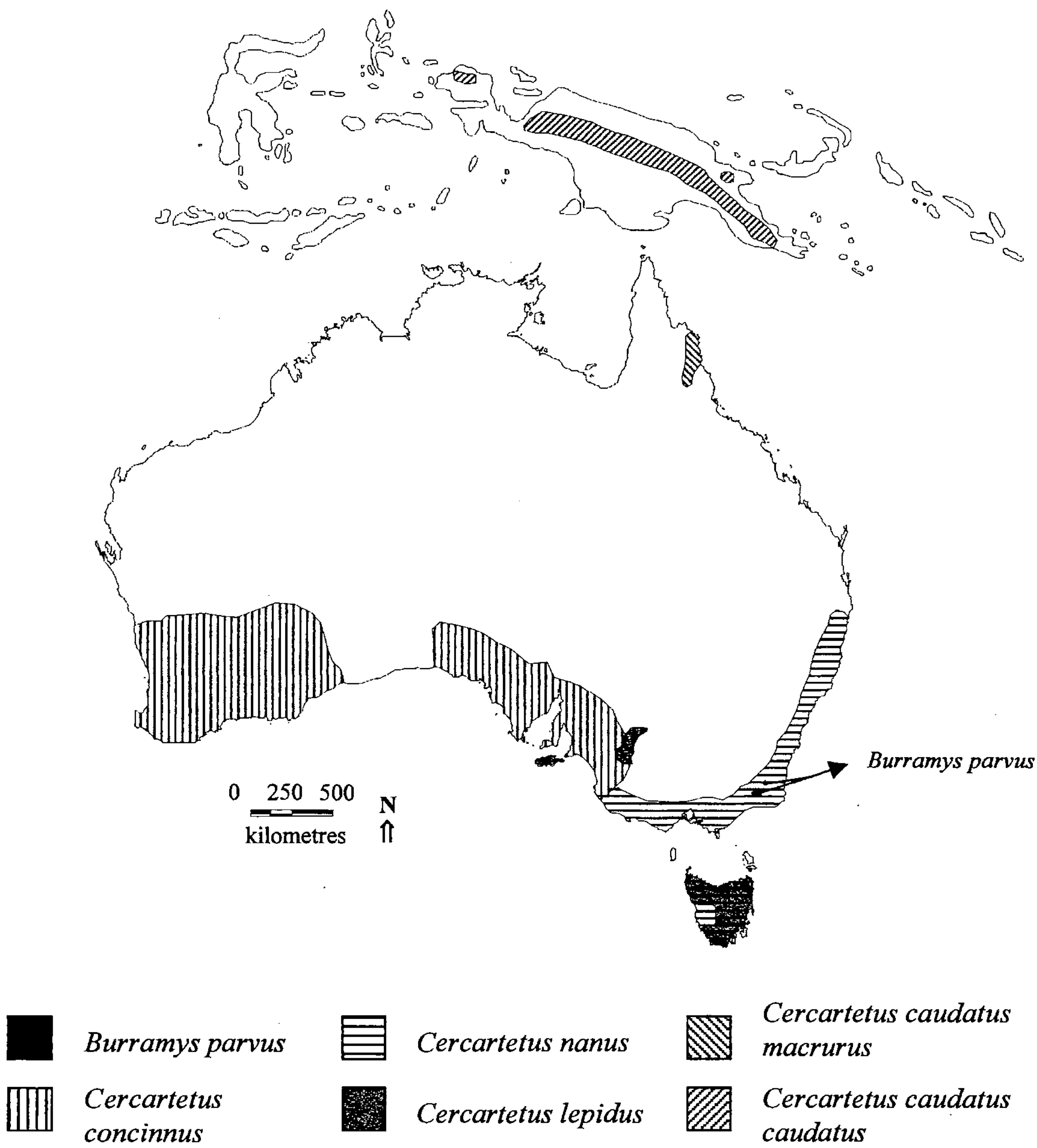

Figure 1.1: Distribution map of Burramys and *Cercartetus* species in Australia and New Guinea (Source: Osborne & Christidis, 2002).

Despite their wide distribution across Australia, little is known about many aspects of the ecology of pygmy possums. Over the past 2 decades fewer than 30 papers have been published on 4 of the 5 species of pygmy-possums. The exception in terms of research effort is *Burramys parvus*, the terrestrial mountain pygmy possum of upland Victoria and NSW, which has received more research interest because of its limited distribution in the Australian alps and recent development of ski resorts within its habitat (Menkhorst & Knight, 2001; Tulloch, 2004).

The lack of information about these species may be due to their small size, cryptic nature and low trapability, as the nocturnal habits and mobility of these possums have made them difficult species for field study (Bowen & Goldingay, 2000). Most research on the species has been confined to laboratory-based work investigating aspects of physiology such as energetics and torpor, behaviour and reproduction (Kortner & Geiser, 1995). Lack of detailed knowledge on the cryptic *Cercartetus* species may be one of the most important factors threatening conservation efforts and the survival of these species (Pestell, 2005).

1.3 THE WESTERN PYGMY POSSUM (*Cercartetus concinnus*)

C. concinnus is a small nocturnal marsupial and is distinguishable from other *Cercartetus* species by the fawn or reddish-brown coloured dorsal fur and completely white ventral fur with a finely-scaled, naked tail (Plate 1.1). Adult western pygmy possums weigh 8-20 g (average 13 g) and have a head/body length of 71-106 mm and a tail length of 71-96 mm (Smith, 1995). *C. concinnus* has a prehensile tail and well-developed toe-pads which aid movement through the foliage. The forefoot, which has small claws on the upper surface of the toes, is used to grasp food while it is being eaten.

Female western pygmy possums also differ from other Burramyids in that they have 6 teats in their anterior-opening pouch rather than 4 (Ward, 1990). Breeding occurs in all months of the year and females can rear 2 or 3 litters in close succession. Female western pygmy possums are thought to reach sexual maturity at 12-15 months. Litter size declines during pouch development with an average of 3.5 young surviving to the late stages of dependent life. The young leave the pouch at around 25 days but remain in the nest (Ward, 1990).

Threats to the western pygmy possum include predation by feral cats and other carnivores and destruction of habitat for rural or urban development. Fortunately the high reproductive rate of *C. concinnus* tends to counter-balance the effect of predation (Smith, 1995).

1.3.1 Diet

Burramyids are thought to be omnivorous to varying extents (Strahan, 1995). The *Cercartetus* species seem particularly adept at changing their diet when resources are fluctuating, either from seasonal influences or other environmental factors such as drought and fire (Tulloch, 2004). Their diet consists of nectar, pollen, insects and other small arthropods and may also include small lizards (Bennett & Lumsden, 1995). The diet of other pygmy possums has been studied in greater detail than that of *C. concinnus*, particularly *B. parvus* (Smith & Broome, 1992; Heinze *et al*, 2004) and *C. nanus* (van Tets & Hulbert, 1999; Tulloch 2004). *Burramys parvus* has highly seasonal food preferences depending on bogong moths (*Agrotis infusa*) and other arthropods in spring and summer, and seeds and berries at other times of the year (Heinze *et al*, 2004). In terms of diet, the eastern pygmy possum, *C. nanus*, appears to be the most studied of all burramyids (Tulloch, 2004). Scat analysis studies of *C. nanus* found that the species is omnivorous, eating a broad range of invertebrates, as well as seeds, nectar and pollen (Tulloch, 2004).

A study of the western pygmy possum's diet in the wild was conducted at Mount Scott Conservation Park, South Australia, by Horner (1994). Horner's study found that western pygmy possums and little pygmy possums (*C. lepidus*) preferred the nectar and pollen of *Banksia marginata* and *B. ornata* over that of *Eucalyptus* species. Invertebrate remains were not detected in scats (Horner, 1994). A study conducted by Pestell (2005), located within Innes National Park, South Australia, looked at scat analysis and pollen swabs from the western pygmy possum. Pestell found the presence of pollen in 36 of 39 scat samples (92.3%) and in 73 of 75 fur samples (97.3%). A high abundance of *Eucalyptus* pollen was found in the faeces of *C. concinnus* but no invertebrate remains (Pestell, 2005). This finding contradicts common assumptions regarding the diet of the western pygmy possum. Strahan (1995) described all pygmy possums as 'primarily' insectivorous and Wakefield's (1963) review of pygmy possums also asserted that arthropods are important components of pygmy possum's diet. Therefore there is much uncertainty and disagreement amongst researchers regarding the diet of the western pygmy possum.

1.3.2 Torpor

Western pygmy possums and other Burramyids are capable of entering deep and lengthy periods of torpor (Geiser & Kortner, 2004). Burramyids generally do not remain torpid for the entire winter. The use of torpor is thought to be opportunistic in the genus *Cercartetus* to cope with periods of low energy levels created by either poor environmental conditions such as low temperatures and/or poor food resources (Geiser & Kortner, 2004). A study of western pygmy possums at Coorong National Park South Australia, determined that individuals entered torpor frequently in autumn, with bouts lasting up to 14 hours (Geiser & Kortner, 2004). Torpor in *B. parvus* is much more seasonal than in other Burramyids, with individuals recorded in bouts of deep torpor or hibernation lasting up to 126 days through the winter (Tulloch, 2004).

1.3.3 Nesting

The majority of species within the suborder Phalangerida (possums and gliders) nest primarily in tree hollows. However honey possums, *Tarsipes rostratus*, do not use nests at all, carrying their young with them in a pouch until almost weaned (Wooller *et al*, 1999). In Australia, tree hollows are used extensively by many species of vertebrates (Lindenmayer *et al*, 1996), including approximately 75% of arboreal marsupials (Smith & Lindenmayer, 1988). During the day *C. concinnus* usually shelters in leaf-lined nests in tree hollows or in the leaves of grass trees (*Xanthorrhoea* sp.) (Misso, 1997). Individuals have also been observed using disused nests of birds (particularly babbler's nests), leaf clumps on the ground, under stumps and hollows in mallee lignotubers at the base of live trees (Smith, 1995).

The benefits of nesting are shelter from environmental conditions and avoidance of predators (Misso, 1997; Kemp, 2001; Vernes & Pope, 2001), as well as the provision of a safe and relatively stable environment for thermoregulation (Rhind, 2003) and rearing young. Shelter from environmental conditions, particularly during colder weather, is likely to be an important consideration in nest site selection, particularly in small mammals which have high metabolic rates (Lazenby-Cohen, 1991; Hume, 2004) and therefore need to conserve energy during periods of low food availability (Geiser & Kortner, 2004). A study conducted by Kemp and Carthew (2004), at Newland Head Conservation Park, South Australia found that western pygmy possums found daytime refuge in debris piles, between dead banksia inflorescences, at the base of *Xanthorrhoea semiplana* or *Banskia ornata* plants, in sedges and in the eucalypt canopy. Interestingly, no animals were followed back to tree hollows during the study (Kemp & Carthew, 2004). It is not known where western pygmy possums in the Western Australian wheatbelt nest, particularly those found in areas of revegetation. For instance do they require nearby older trees for hollows given young plantations are devoid of such habitat?

1.3.4 Movement Patterns

Little information exists on the social organisation, movements, size and spacing of home ranges of the western pygmy possum (Bennett & Lumsden, 1995). However, in south-east South Australia, the mean distance travelled by individuals between captures ranged from 24 m to 60 m and the maximum distance recorded between captures was 195 m (Horner, 1994). A study of a population of eastern pygmy possums (*C. nanus*) conducted by Bladon *et al* (2002) in Northern New South Wales found that distances covered by pygmy possums during a single night varied from 72 to 450 m. Males tended to move greater distances than females and males had significantly larger home ranges than females. On average the home range of females was only 40% that of males. During the study pygmy possums were observed nesting in multiple numbers and of these multiple nestings, 48% were mothers with young (Bladon *et al*, 2002).

1.4 SIGNIFICANCE OF THIS STUDY

Effective management and conservation of arboreal marsupials requires detailed knowledge of their habitat requirements (Kemp & Carthew, 2004). There have been few targeted studies on the western pygmy possum and there is clearly a need for further research on this small, cryptic species. The utilisation of farm tree plantations by the western pygmy possum was an unexpected discovery and therefore little is known about the habitat value and usage of these farm tree plantations by the western pygmy possum. As a group, possums and gliders are recognized as being particularly susceptible to habitat loss because of their reliance on intact forest and woodland. Other potential threats to possums and gliders are predation by introduced carnivores, a reduction in the availability of hollows, competition with introduced species for hollows and wildfires (Gibbons & Boak, 2002). If farm tree plantations can provide suitable habitat for the western pygmy possum then animal may not be as susceptible to the continual loss and habitat fragmentation of remnant vegetation. It is anticipated that this study will provide a better understanding of the habitat values of farm tree plantations to the species and that this knowledge can be communicated to landowners and environmental managers. Landowners could be encouraged to make minor changes to the design and management of farm tree plantations that will enhance wildlife conservation for species such as the western pygmy possum. It is hoped that this study can improve the public-profile of the western pygmy possum to ensure continued support for conservation and management initiatives.

1.5 AIMS

This study will attempt to determine habitat utilisation patterns of the western pygmy possum by tracking the movement of the species at farm tree plantation sites where they are abundant. The characteristics of farm tree plantations in the wheatbelt region of Western Australia, within the shires of Narrogin, Cuballing and Wickepin that provided a suitable habitat for the western pygmy possum (*Cercartetus concinnus*) will then be determined.

The aims and hypotheses of the study are:

1. Determine habitat utilisation patterns of the western pygmy possum (*Cercartetus concinnus*) by tracking the movement of the species at farm tree plantation sites where they are abundant;

Null Hypothesis: Western pygmy possums (*Cercartetus concinnus*) found within the study area do not spend a longer period of time in vegetation that is flowering than in vegetation that is not flowering.

2. Describe selected characteristics of farm tree plantations that provide a suitable habitat for the western pygmy possum (*Cercartetus concinnus*);

Null Hypothesis 1 *(LOCAL SCALE):* Western pygmy possums (*Cercartetus concinnus*) found within the study area are not more abundant in oil mallee plantations than in mixed revegetation or remnant vegetation.

Null Hypothesis 2 *(LANDSCAPE SCALE):* Western pygmy possums (*Cercartetus concinnus*) found within the study area are not more abundant in isolated vegetation than that which is well connected, at the landscape scale, to remnant vegetation.

Following the completion of the aims listed above, recommendations will be given to local farmers on how to manage and/or modify farm tree plantations to enhance their biodiversity value within the landscape.

1.6 THESIS STRUCTURE

Chapter 2 provides a description of the research area detailing the climate, geology and soils and flora and fauna of the wheatbelt region of Western Australia. The chapter justifies the selection of the 14 study sites within the shires of Narrogin, Cuballing and Wickepin. The sites are then described and illustrated.

Chapter 3 describes the methods used throughout the study for each of the aims. Trialled methods used during the study are also described and are discussed as to why they were unsuccessful.

Chapter 4 addresses the first aim of the study and presents the habitat utilisation patterns of the western pygmy possum as determined by tracking the movement of the species at farm tree plantation sites where they were abundant. The chapter also addresses the second aim of the study by describing the characteristics of farm tree plantations that provide a suitable habitat for the western pygmy possum (*Cercartetus concinnus*).

Chapter 5 provides a discussion of the results for both of the aims and a conclusion for the study.

CHAPTER 2: RESEARCH AREA & STUDY SITES

2.1 INTRODUCTION

This research was based in the West Australian southern wheatbelt (Figure 2.1). All study sites were situated on farms throughout the Shires of Narrogin, Cuballing and Wickepin. The largest of these towns is Narrogin, with a population of approximately 4,424, which is located 192 km south-east of Perth on the Great Southern Highway between Pingelly and Wagin (Figure 2.2).

2.1.1 Description of Research Area

The wheatbelt region of Western Australia covers 155,256 km^2. It is comprised of 44 local government authorities and contains the majority of the State's grain growing areas (Wheatbelt Development Commission, 2003). The region partially surrounds the northern and eastern parts of the Perth metropolitan area. It extends north from Perth where it meets the Mid-West Region and is bordered by the Indian Ocean to the west. The wheatbelt extends east from the metropolitan area to the mining dominated, Goldfields-Esperance Region. The region is also bordered by the Peel, the South West and Great Southern regions on its south-west and southern borders (Wheatbelt Development Commission, 2003) (Figure 2.1).

Clearing of land for cropping and grazing first began in the south-west of Western Australia at the time of initial settlement in 1829. However, population growth and thus agricultural development was slow. By 1900, only 30,000 ha of land was under wheat production. The greatest periods of clearing were in the period following World War I, before the 1939 depression and following World War II (Burvill, 1956). By 1985, the area sown to wheat exceeded 4.6 million ha (Schofield *et al*, 1988). It is estimated that only 7% of the pre-European vegetation in the entire wheatbelt region of Western Australia has been retained (ABS, 2006). The remaining vegetation exists as national parks, nature reserves, scattered remnants on private land or other categories of Crown land (including vacant Crown land) (Hamilton *et al*, 1991).

The wheatbelt's economy has historically been based on agriculture, particularly cropping, which remains the most dominant industry in the region. It also has mining, commerce, manufacturing, fishing and tourism industries, which make notable contributions to the regional economy. Total agricultural production was valued at $2.2 billion in 1999/00 and was comprised mostly of wheat, which was valued at $1.2 billion

(Wheatbelt Development Commission, 2003). The wheatbelt region has the third largest population of the State's nine non-metropolitan regions with an estimated population of 72,282 in 2002. In 2003 it had 3.8% of the State's population and 13.8% of regional Western Australia's population (Wheatbelt Development Commission, 2003).

2.1.2 Climate

The research area has a mediterranean climate with hot dry summers and cool wet winters. Rainfall varies from 600 mm per annum on the western side of the wheatbelt to 300 mm on the eastern side. Some 75% of the annual rainfall of this region occurs during the six cool months from April to September when low pressure systems originating in the Indian Ocean move past the south west corner of the state. At the end of this period a belt of high pressure lying across the continent moves south and, centred over the southern ocean, produces an easterly wind pattern and high temperatures. The long hot summers mean that vegetation is highly combustible and fire has long been a characteristic of the region and important in the evolution of its flora (Lefroy *et al*, 1992).

2.1.3 Geology and Soils

The wheatbelt's landscape has been subjected to continual erosion and leaching over thousands of years. Today this landscape can be described by three main landforms; the upland sandplains, the valley slopes and the valley floors. These landforms represent a transition from the coarse textured sands and gravels of the uplands, through the sandy clays and loams of the slopes to the fine textured clays of the valley floors. Within these landforms, wind and water have shaped and re-shaped the surface many times resulting in a complex mosaic of different soil types (Lefroy *et al*, 1991).

The geology of the most northerly, inland section of the wheatbelt is mainly sedimentary basins exposing Permian to Cretaceous sediments. The coastal northern wheatbelt has Mesozoic to recent sediments, while the base rock of the central wheatbelt around Northam is Archaean granites with infolded metamorphics of the Yilgarn Block. The southern wheatbelt is Archaean and Proterozoic granites, but they were laterised in the Tertiary, with this laterite eroded away throughout most of the landscapes except for the hill tops, especially to the east. In the very south-east mainly Eocene sediments with outcrops of granites and quartzites occur (Beard, 1981).

It has long been recognised that most Western Australian soils are of low to extremely low natural fertility. This is because of the great age of the landscape and the low levels of phosphate in the underlying rocks (especially laterite). The only soils possessing reasonably natural fertility in the wheatbelt are some of the young soils of alluvia or fresh rock. As a consequence of low fertility, the use of super-phosphate to enrich the soils used for agriculture was introduced in the 1890s (Beard, 1981).

Ocean-derived salt is continuously transported inland and deposited with rainfall. In the central wheatbelt the amount of salt stored in the soil profile varies from an average of 247 tonnes ha^{-1} upslope to around 13,500 tonnes ha^{-1} in valley floors (McFarlane *et al*, 1993). As a result of clearing of the original deep-rooted vegetation, water tables in some places have risen over 20 m since the 1920s and salt is coming to the surface (George *et al*, 1995). Western Australia has the largest area of dryland salinity in Australia and the highest risk of increased salinity by 2050. An estimated 4.3 million ha (16%) of the south-west region has a high potential of developing salinity from shallow watertables. This is predicted to rise to 8.8 million ha (33%) by 2050. The eastern wheatbelt and eastern sections of the northern wheatbelt exhibit high risk of salinity expansion by 2050 (National land & water resources audit, 2001).

2.1.4 Flora and Fauna

Prior to European settlement, Western Australia's wheatbelt area was covered by a complex mosaic of woodland, mallee, shrublands, granite rock communities and salt-land plants (Hobbs & Wallace, 1991). Clearing has left only remnant areas, most of which are quite small. Fire frequency and intensity has changed in the region and consequently, the natural cyclical succession of assemblages of species is altered. Understorey in some fragments is lost as a result of grazing and trampling by stock. These changes combined with the decrease in area of vegetation types, has resulted in the loss of plant and animal species at particular localities, or in some cases extinction (Jenkins, 1998).

The wheatbelt region has a diverse flora and fauna despite the habitat loss. It is amongst the most diverse in the world with most species unique to the region (Coates, 1987). There is a particularly high density of rare and geographically restricted plant species (Hopper, 1986). Nonetheless, of the 43 species of mammal known to inhabit the area at the time of European settlement, 17 are now regionally extinct (Friend, 1987). Other species such as the red-tailed wambenger (*Phascogale calura*), the numbat

(*Myrmecobius fasciatus*) and the tammar wallaby (*Macropus eugennii*) are restricted in their distribution (Christensen & Maisey, 1987). Many of the plant and animals that still survive are under threat due to the ongoing degradation of the many vegetation fragments (Jenkins, 1998).

Figure 2.1: Key features of the wheatbelt region of Western Australia (Source: Wheatbelt Development Commission, 2003).

2.2 STUDY SITES

2.2.1 Selection of Study Sites

The 14 sites in this study were selected because they had the highest recordings of western pygmy possums over the three year Biodiversity Value of Oil Mallee Farming Systems project conducted by CSIRO. Results from the first survey conducted by CSIRO in 2005 showed that a wide variety of native animals including the western pygmy possum can be found in the oil mallee plantations. Nine of the 14 sites in my study were oil mallee plantations and the other five sites were mixed revegetation plantations. Sites were chosen where western pygmy possums had been trapped during CSIRO's project so the species could be trapped and radio tracked in my project to enable the habitat characteristics that the plantations were providing for the species to be described.

2.2.2 CSIRO Project Study Sites

Between 2005 and 2007 surveys were conducted by the CSIRO on 30 farms, using 108 sites in the shires of Narrogin, Cuballing and Wickepin of the Western Australian wheatbelt as part of the project entitled the Biodiversity Value of Oil Mallee Farming Systems (Figure 2.2). The sites were made up of remnant vegetation, mixed revegetation and oil mallee plantation. Data relating to the western pygmy possum was made available for this study.

Figure 2.2: The study area circled in red of the shires of Narrogin, Wickepin and Cuballing (Source: Smith, 2004).

2.2.3 Honours Project Study Sites

Of the 108 sites used in the study conducted by CSIRO, this project utilised 14 of these on 4 of the 30 total farming properties. The four different properties were Hesfords, Gaths, Nottles and Rose Rd. Three of the 5 sites at the Hesford property were in oil mallee plantations (CSIRO sites 58, 59 & 60) and the remaining 2 sites were in mixed revegetation (CSIRO sites 55 & 56) that had been planted by the land owner (Plates 2.1 & 2.2). The 3 sites at the Gath property were in oil mallee plantations (CSIRO sites 40, 41 & 42) that had been planted by the land owner (Plate 2.3). The 3 sites at the Nottle property were also in oil mallee plantations (CSIRO sites 34, 35 & 36) that had been planted by the land owner (Plate 2.4). The 3 sites at Rose Rd were in mixed revegetation (CSIRO sites 76, 77 & 78) that had been planted next to an area of remnant vegetation (Plate 2.5).

Plate 2.1: Oil mallee plantation at the Hesford property.

Plate 2.2: Mixed revegetation at the Hesford property.

Plate 2.3: Oil mallee plantation at the Gath property.

Plate 2.4: Oil mallee plantation at the Nottle property.

Plate 2.5: Mixed revegetation at Rose Rd.

CHAPTER 3: METHODS

3.1 INTRODUCTION

In this chapter the general study approach will first be outlined followed by the specific methods of data analysis used for each of the study aims.

3.2 HABITAT UTILISATION PATTERNS

Pitfall traps provide the most effective means of capturing the smallest terrestrial mammals and these were used to capture western pygmy possums for radio tracking (McComb *et al*, 1991). A pitfall trap is a container placed in the ground so that its open end is flush with the surface. Animals are captured when they fall through the opening into the container below. Capture rates of most species of small terrestrial mammals are enhanced greatly if pitfall traps are operated in conjunction with a drift fence that crosses the open pits. A drift fence is a barrier designed to direct small mammals into the pitfall traps.

Existing pitfall traps set up by CSIRO were utilised. The pitfall trap system used employed a series of three 20 l plastic buckets buried to the rim (sealed with steel lids when not in use). The buckets were arranged in a 'Y' configuration with one bucket midway along each of the three 'arms' made of plastic garden edge 10 m long × 15 cm high (Plate 3.1). The pitfall traps used in this project were designed for live capture. The pitfall buckets had an opening diameter of 28.5 cm and were 40 cm deep so that the small mammals could not escape. The bottoms of the buckets were lined with pieces of insulation batts and small sheets of polystyrene to provide a refuge, heat insulation and flotation devices should rain occur during trapping (Plate 3.2).

Pitfall traps were opened at sunset on the first day of trapping and examined before 8 am each day of the trapping period. When a western pygmy possum was captured, sex, presence/absence of pouch young and life stage (adult/juvenile) were recorded. The western pygmy possum was then placed in a calico bag and transferred into a small cage with adequate shelter and natural vegetation. The captured western pygmy possums were kept until the night when they were to be tracked. Each pygmy possum was kept no longer than 10 h before being released. Western pygmy possums were kept and released at night so they would have a better chance of avoiding predators. Any additional pygmy possums not used for radio tracking were also kept in a holding cage during the day then marked with a non-toxic marker on their stomach to show that they had been captured and released at night. Any other captures such as frogs, skinks and insects were released immediately. Trapping periods ranged from 1 to 10 nights with a total of 39 trapping nights from May until September. A total of 17 (three recaptures) western pygmy possums were trapped during this period, 12 males and five females.

Plate 3.1: Pitfall traps with drift fence in mixed revegetation.

Plate 3.2: A pitfall trap bucket lined with pieces of insulation batts and small sheets of polystyrene with a drift fence running through the middle.

Radio tracking was undertaken to determine habitat utilisation patterns of the western pygmy possum after their release at sites where they were captured. At night, when the captured pygmy possum was to be tracked it was transferred from the small holding cage into a calico bag and taken back to the capture site. A single stage transmitter (Titley Electronics, LTM 337), with a 10 cm trailing antenna and a maximum battery life of 15-16 days, which weighed less than 0.55 g [which is less than the suggested maximum load increase of 5% of the possum's body weight (Cochran, 1980)] was then attached to the back of the pygmy possum. Non-toxic glue was used to attach the transmitter to the tips of the pygmy possum's fur, making no contact with the skin (Plate 3.3). The pygmy possum was then marked with a non-toxic permanent marker on its stomach to show that it had been tracked. At any one time, only one pygmy possum was fitted with a radio transmitter and its movement tracked on foot.

Tracking occurred at different times and for varying periods of time during the night. Some pygmy possums were tracked for more than one night and tracked to their nest site during the day. The transmitter uses a specially made crystal that employs a particular frequency, which is recognized by the radio tracking equipment. The radio tracking equipment can pick up this frequency approximately 500 m away. Therefore, to determine the exact location of the pygmy possum the radio tracking equipment was gradually set further off the transmitter's frequency so that a faint signal could only be picked up exactly where the pygmy possum was – this enabled the direction of the western pygmy possum from the observer to be determined. At every five minute interval the location of the pygmy possum was determined and this location was marked with flagging tape. At this five minute interval the following observations were recorded:

- Behavioural observations: is the pygmy possum feeding (and what is it feeding on), sitting, moving or nesting?
- Movement: how far has the pygmy possum moved from the last location?
- Habitat: is the pygmy possum in a certain kind of vegetation or is it on the ground?

During the day, measurements were taken at each of the locations marked by the flagging tape. These measurements were:

- Leaf litter cover in a 2 m × 2 m quadrat (%);
- Leaf litter depth (cm);
- Tree cover (%);
- Tree height (m);
- Tree crown height (m);
- Distance between tree crowns (m);
- Length of connecting tree crowns (m);
- Tree hollow height off the ground (m);

- Tree hollow diameter at widest point (cm) and
- Presence of flowers using the ordinal scale: 0= No flowers, 1= Minimal flowers, 2= Medium number of flowers, 3= Prolific flowers.

Radio transmitters were removed at the end of the tracking period by using a scalpel to shave the tips of the fur away from the transmitter without harming the pygmy possum and the pygmy possum was then released.

Plate 3.3: A western pygmy possum (*Cercartetus concinnus*) with a transmitter glued to its back.

GPS coordinates were recorded at each of the locations marked by the flagging tape. Using ARCGIS (Version 10) these coordinates were then placed over aerial photographs of the area to produce a map of the habitat utilisation patterns for each pygmy possum tracked.

3.2.1 Data Analysis

Null Hypothesis: Western pygmy possums (*Cercartetus concinnus*) found within the study area do not spend a longer period of time in vegetation that is flowering than in vegetation that is not flowering.

A one-way analysis of variance (ANOVA) (SPSS for Windows v. 14) was used to compared the mean time (minutes) western pygmy possums spent in oil mallees of differing flowering levels (0= No flowers, 1= Minimal flowers, 2= Medium number of flowers, 3= Flowering prolifically), but the variances were significantly different which violated one of the basic assumptions of ANOVA. Therefore the non-parametric Kruskal-Wallis test was used to compare the data.

A scatter plot was also used to describe the nature of the relationship between the independent variable (Oil mallee flowering) and dependent variable (time in minutes). A line of best fit was then drawn to observe the trend and enable predictions to be made on the basis of the data (Microsoft Office Excel 2003).

3.3 HABITAT CHARACTERISTICS

The characteristics of farm tree plantations that provide a suitable habitat for the western pygmy possum were determined using data relevant to the western pygmy possum and associated vegetation variables. This data was collected from the Biodiversity Value of Oil Mallee Farming Systems project undertaken by the Commonwealth Science and Industry Research Organisation (CSIRO) in Perth Western Australia. This broader project aimed to determine whether oil mallee plantations on farms provide additional habitat for native animals, and if so how they compare to other types of natural and planted vegetation in the landscape.

Surveys were conducted on 30 farms, using 108 sites in the Narrogin region of the West Australian wheatbelt (Smith, 2004). A survey was conducted throughout the study area detailing various local vegetation variables (Table 3.1). In addition, landscape scale variables were generated by geographical information systems (GIS) (Table 3.2). Species abundance was determined by using focal observations to determine bird counts, pitfall traps, cage and Elliott traps to capture small vertebrates including frogs and invertebrates. The Biodiversity Value of Oil Mallee Farming Systems project explored the general habitat value of oil mallee plantations on farms, whereas this honours project specifically analysed a subset of this data related to the western pygmy possum which had not previously been analysed.

3.3.1 Data Analysis

Null Hypothesis 1 *(LOCAL SCALE):* Western pygmy possums (*Cercartetus concinnus*) found within the study area are not more abundant in oil mallee plantations than in mixed revegetation or remnant vegetation.

Null Hypothesis 2 *(LANDSCAPE SCALE):* Western pygmy possums (*Cercartetus concinnus*) found within the study area are not more abundant in isolated vegetation than that which is well connected, at the landscape scale, to remnant vegetation.

A one-way analysis of variance (ANOVA) (SPSS for Windows v. 14) was used to compare the mean abundance of western pygmy possums at sites of three different vegetation types (as described in the hypotheses above), but the variances were significantly different which violated one of the basic assumptions of ANOVA. Therefore the non-parametric Kruskal-Wallis test was used to compare the data. Species abundance in my study refers to the total number of western pygmy possums caught over the trapping periods. Where a particular category had only 1 sample (i.e. n = 1), this category was combined with an adjoining category so that n > 2. For example, because only 1 site had 8 pygmy possum captures and 1 site had 6 captures, these 2 sites were combined with those at which 4 were caught to form a group of sites with 4 or more captures. This enabled ANOVA to be performed on these variables with single data points in certain categories.

Generalised linear regression (G.L.R) analysis (GENSTAT 10th Ed.) was used to explore relationships between the western pygmy possum abundance and the environment, on the basis of observations on the species and environmental variables at a series of sites. A Poisson error distribution was specified for the data. A log link function was used between the species abundance and predictor variables. Each analysis focussed on how the western pygmy possum was related to particular environmental variables such as leaf litter cover. The species abundance was the response variable and the environmental variables were the explanatory variables. The analysis allowed, through tests of statistical significance the assessment of which environmental variables contribute most to the species' response and which environmental variables appear to be unimportant.

The CSIRO data relating to the western pygmy possum was firstly organised into factors and variates based on whether the data was categorical or continuous. Each of the environmental variables were then analysed using generalised linear regression to determine the relationship with the abundance of the western pygmy possum. Variables were selected which best explained the variability.

Scatter plots and linear regression were used to explore relationships between individual vegetation variables and the abundance of western pygmy possums to try and determine why western pygmy possums were more or less abundant at particular vegetation types. ANOVA tests were also used to compare mean abundance of western pygmy possums between various classes of categorical variables at both local and landscape levels. ANOVA tests were used on all sites (including oil mallee plantations, mixed revegetation and remnant vegetation) and also just on farm plantation sites (oil mallee plantations and mixed revegetation) to determine why western pygmy possums were more or less abundant at different farm plantation sites. Where Levene's test demonstrated unequal variances between classes, a non-parametric alternative, the Kruskal-Wallis (KW) test was used to determine differences. Games-Howell post-hoc test was used to establish which classes were different from one another.

Table 3.1: Table of local scale vegetation variables measured at study sites for the Biodiversity Value of Oil Mallee Farming Systems project for CSIRO in 2005.

Variable	Measurement
Vegetation type one	Oil mallee plantation, revegetation or remnant
Vegetation type two	E.g. wandoo woodland, mallee, gimlet woodland, tammar shrubland or saltbush
Vegetation a block or alley	Block/alley
Site adjacent to (within 10m) an existing remnant of native vegetation	No, yes-but remnant in poor condition, yes-but remnant in moderate condition, yes-remnant in good condition
Local native tree species (>4m)	Number per 50×20m plot
Local native shrub species (<4m)	Number per 50×20m plot
Local native perennial grass, sedge & rush species	Number per 20×20m plot
Local native perennial forb species	Number per 20×20m plot
Local native annual species	Number per 20×20m plot
Vegetation life form present at stratums 1 to 5 (form: tree, mallee, shrub, perennial herbaceous)	Estimated height and % cover class from <2% to >70%
Height of vegetation at stratums 1 to 5	Metres
Plant cover for all life forms of vegetation stratums 1 to 5 including cryptogams	% classes from nil to >70%
Tree health problems (e.g. dieback, insect damage etc)	From none affected to all or most trees affected (>70%) canopy
Ground cover of cryptograms, litter <1cm, litter >1cm, perennials, annuals, annuals native, annuals introduced, bare soil	% cover from nil to 100%
Bare soil	Loose or apparently stable
Intact of interconnecting shrubland/heathland canopy offering nesting & foraging habitat for fauna	% cover from nil to >40%
Evidence of recruitment from volunteer & planted species	Species and number of recruits
Large trees	Number per 50×20m plot
Trees with visible hollows (>5cm diameter)	Number per 50×20m plot
Wood load	Total length (m) of logs >10cm diameter per 50×20m plot
Presence of coarse woody debris (bark, sticks and branches <10cm diameter)	% cover from nil to >30% of site covered
Presence of rocks >10cm diameter &/or boulders on the ground	% cover from nil to >30% of site covered
Severity and aerial extent of soil erosion associated with site	% class from minimal (<20% of site) to severe (>75% of site)
Livestock grazing intensity & access to remnant native vegetation & water	Classes from set stocked to never/rarely intentionally grazed
Fire management regime, intensity & frequency	Three classes: Site not burned in past 20+ year, site hazard reduction burnt every 10+ years or site wild-fired or deliberately burned every 2-3years
Floristic composition of weeds present at site	Classes from no weed species present to >10 weed species present
Incursion distance of weeds into native vegetation remnants up to 100m from remnant edge an in proximity to site	Classes from weeds do not occur beyond 10m into remnant to weeds occur 100m into remnant
Presence of weeds in native vegetation remnants as % projective foliage cover within 100m of remnant edge	Classes from weeds <5% projective foliage cover to >70%
Feral animals & livestock on site	Presence detected by identification of scats etc
Drainage lines depth	Metres
Drainage lines width	Metres
Number of woody perennial stems	In $1000m^2$

Table 3.2: Table of landscape scale vegetation variables measured at study sites for the Biodiversity Value of Oil Mallee Farming Systems project for CSIRO in 2005.

Variable	Measurement
Vegetation isolated or adjacent to other vegetation	Isolated/adjacent
Area of remnant vegetation within a 100 ha circle from site	Hectares
Area of remnant vegetation within a 1,000 ha circle from site	Hectares
Area of remnant vegetation within a 10,000 ha circle from site	Hectares

3.4 TRIALLED METHOD

In addition to the methods described under the study aims another method was trialled, fluorescent-powder tracking. However, this method of tracking was not continued throughout the project. This supplementary method is described here as it is somewhat novel and makes an important contribution to the study of pygmy possums and other small mammals.

Fluorescent-powder tracking involves a fine fluorescent powder to be dusted onto the animal, when the animal is released the powder is deposited as it moves. The trail of powder leaves a record of the animal's movements traceable by an ultraviolet light (Stapp *et al*, 1994). Pitfall traps were opened at sunset and examined every two hours until a pygmy possum was caught; all the pitfall traps were then closed. The captured pygmy possum then had the fluorescent powder applied to its body and was marked with a non-toxic permanent marker on its stomach to show that it had been tracked. Any additional pygmy possums or other species such as lizards that were caught were released immediately.

Each western pygmy possum had the fluorescent powder applied to its body only once, since the powder may accumulate within the body tissues of the pygmy possum with repeated exposures over a short time span (Stapp *et al*, 1994). The pygmy possum's head was pushed through a small hole in the corner of a plastic bag and powder applied to the body with a plastic squeeze bottle. This limited the exposure of respiratory tissues to the powder particles and minimized the inhalation of powder by the pygmy possum. The western pygmy possum was then released at the site of capture and the fluorescent powder trail followed.

A marker was placed at 1-2 m intervals so that the trail could be examined in daylight. Habitat characteristics were then to be measured at each marked interval, such as the percentage of ground cover, number of large trees, number of native shrubs and vegetation height. Vegetation height was to be measured using a pole which had been divided into 20 cm intervals and placed vertically into the vegetation stratum. The number of points of contact between vegetation and the pole would then be counted for each 20 cm height interval between 0 and 1 m. These vegetation characteristics were also to be measured along control trails within the capture sites, each consisting of a straight 40 m transect along a random bearing from each trap site replicated five times in order to assess the general characteristics of the microhabitat available at the site. Chi-squared analysis would then be undertaken to compare the distribution of the fluorescent powder trails within the capture site in regards to habitat characteristics compared to the spatial distribution of the habitat characteristics.

A total of three western pygmy possums were tracked using this method, however this method of tracking did not prove to be successful. Tracing the trail of fine fluorescent powder deposited by the pygmy possum was very time consuming and difficult. It was thought that perhaps the fluorescent powder trails would light up better following sunset, after the fluorescent powder had been charged by the sun during the day, however this did not prove to be the case. It was decided that this method of tracking would no longer be used and instead all pygmy possums were tracked using radio tracking techniques.

CHAPTER 4: RESULTS

4.1 HABITAT UTILISATION PATTERNS

4.1.1 Captures

During this study over the months of May to September, a total of 39 trapping nights resulting in 17 captures of the western pygmy possum (Table 4.1), gave an overall trapping success of 43.6%. A total of 12 males and 5 females were caught, 1 of the females was carrying pouch young and 1 male and 1 female were juveniles. Of the 17 captures 3 of the pygmy possums were recaptures. Eight individual possums were radio tracked, 5 males and 3 females (Table 4.2). Only 8 out of the 14 western pygmy possums caught were radio tracked because one western pygmy possum could only be tracked at a time and on some nights multiple western pygmy possums were caught. A total of 13 of the 14 western pygmy possums caught were trapped in oil mallee plantations, the remaining animal was trapped in mixed revegetation. Site 35, in a row of oil mallees, had the most captures with 5 western pygmy possums of different sexes and ages being trapped there over a number of days.

Table 4.1: Western pygmy possums (*Cercartetus concinnus*) caught in pitfall traps on properties within the Shires of Narrogin, Cuballing and Wickepin in the wheatbelt region of Western Australia between May and September 2007, over a total of 39 trapping nights.

Date Caught	Site Number	Male/Female	Tracked? Y/N	Recapture? Y/N
22/05/07	36	M	Y	N
05/06/07	59	M	N	N
05/06/07	59	M	Y	N
07/06/07	58	F	Y	N
07/06/07	56	M	Y	N
07/06/07	60	M	N	N
07/06/07	59	M	N	N
07/06/07	59	M	N	N
23/07/07	35	M	Y	N
15/08/07	34	F (Pouch Young)	N	N
01/09/07	36	M	Y	N
04/09/07	36	F	Y	N
04/09/07	35	M (Juvenile)	N	N
04/09/07	35	F (Juvenile)	N	N
06/09/07	35	M	Y	Y
10/09/07	36	F (Juvenile)	Y	Y
10/09/07	35	M (Juvenile)	N	Y
TOTALS: (Total Trapping Nights: 39)		**10 Male 4 Female**	**Tracked: 8**	**Recaptures: 3**

Table 4.2: Tracking dates and periods that the eight western pygmy possums (*Cercartetus concinnus*) were radio tracked, at sites within the Shires of Narrogin, Wickepin and Cuballing in the wheatbelt region of Western Australia.

Pygmy Possum No.	Site Captured	Male/Female	Nights Tracked	Times Tracked	Total Time Tracked (hours)
1	59	M	05/06/07 06/06/07	9:51pm-1:01am 6:15pm-7:45pm	4 h 40 min
2	58	F	08/06/07 09/06/07 11/06/07	7:15pm-8:15pm 7:30pm-10:30pm 10:30pm-2:00am	7 h 30 min
3	56	M	08/06/07 10/06/07	7:30pm-7:35pm 6:00pm-9:00pm	3 h 5 min
4	36	M	22/05/07 23/05/07	11:40pm-12:20am 9:30pm-10:00pm	1 h 10 min
5	35	M	23/07/07 24/07/07	9:00pm-9:40pm 7:30pm-9:30pm	2 h 40 min
6	36	M	01/09/07	7:30pm-10:40pm	3 h 10 min
7	36	F	04/09/07	7:30pm-9:30pm	2 h
8	36	F	10/09/07	7:50pm-8:30pm	40 min
TOTALS:		**5 Male 3 Female**	**14 Nights**		**24 h 55 min**

4.1.2 Feeding Observations

There was a gradual increase in the time the western pygmy possums spent over the 3 categories of flowering oil mallees (KW test: $X^2 = 17.9$; $p = <0.001$). As the availability of flowers on oil mallee trees increased, the amount of time the western pygmy possums spent in the trees also increased (which rejects the null hypothesis) (Figure 4.1). Whilst radio tracking, the western pygmy possums were observed to spend longer periods of time in the oil mallees that were flowering prolifically than in oil mallees with none to a minimal number of flowers. The pygmy possums were observed to move quickly and effortlessly through the canopies seeking out oil mallees that had an abundance of flowers (Plate 4.1). The pygmy possums were observed to use the non-flowering canopies as a means to reach the flowering canopies without having to move across the ground. Once in the flowering oil mallees the pygmy possums were observed moving up and down the canopy from flower to flower feeding on the nectar for up to an hour in each tree. All 8 of the western pygmy possums radiotracked were observed feeding on the nectar in the flowers of oil mallee trees. The western pygmy possums were never observed feeding on any other source of food, which is an unusual observation as the diet of western pygmy possums is thought to consist of nectar, pollen, insects and other small arthropods and may also include small lizards (Bennett & Lumsden, 1995).

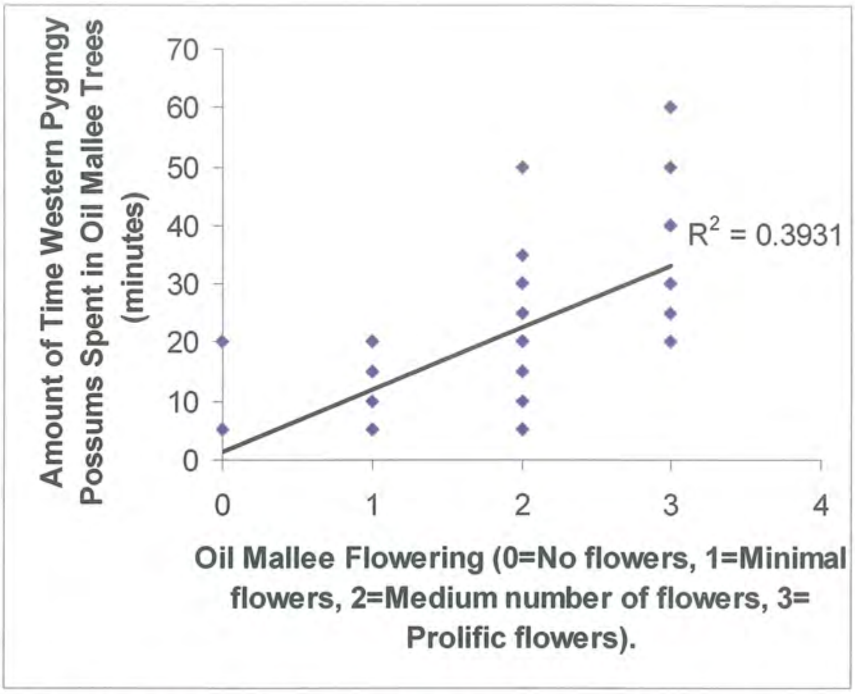

Figure 4.1: A trend between the amount an oil mallee is flowering and the amount of time a western pygmy possum (*Cercartetus concinnus*) spent in the oil mallee at sites in the Shires of Narrogin, Wickepin and Cuballing in the wheatbelt region of Western Australia.

Plate 4.1: A western pygmy possum (*Cercartetus concinnus*) with the tracking transmitter visible (identified with an arrow), that was being tracked in an oil mallee plantation.

4.1.3 Nesting Sites

Six of the 8 western pygmy possums were radio tracked back to their nesting sites. All 6 of these pygmy possums were found to use the hollows of *Eucalyptus wandoo* (white gum) trees as nesting sites (Plate 4.2). Two of these white gum nesting trees were found amongst road-side vegetation. One white gum nesting tree was among a fenced off remnant vegetation strip in a paddock that had been surveyed for a road that is yet to be built. Three of the white gum nesting trees were paddock trees. A group of 3 western pygmy possums (female, male and juvenile) were also found nesting below the bucket of a pitfall trap under the ground in an oil mallee plantation. A small hole was in the ground at the edge of the pitfall bucket and the pygmy possums had made a nest of dried grass under the base of the bucket.

Plate 4.2: A *Eucalyptus wandoo* (white gum) tree with hollows (identified with arrows) that was used as a nesting site by a western pygmy possum (*Cercartetus concinnus*).

4.1.4 Movement Patterns

Male western pygmy possums tended to travel further distances than females. The longest distance travelled from a nest site was 400 m by a male western pygmy possum, number 3 (Table 4.3). The longest distance travelled by a western pygmy possum which included the distance from the nesting site and the distance travelled while feeding was 443 m over 3 h and 10 min (male number 6). This western pygmy possum was observed moving rapidly through the oil mallee canopies feeding on the nectar from the flowers, moving up and down the row of trees throughout the tracking period. Western pygmy possum numbers 3 and 5 did not move at all from their nesting sites throughout the second tracking periods. Although it is unlikely, this may have been because the transmitter had fallen off into the hollow of the tree (Table 4.3). Figures 4.2 and 4.3

provide the habitat utilisation patterns of the 8 western pygmy possums tracked, mapped over aerial photographs of the area. Western pygmy possums are thought to enter periods of torpor to overcome low energy levels created particularly by poor environmental conditions such as low temperatures and/or rain (Geiser & Kortner, 2004). However, 1 male western pygmy possum (number 5) was found curled up clinging to a branch of an oil mallee tree (but not in a state of torpor) while it was raining heavily. This western pygmy possum had moved from its nesting site during unfavourable environmental conditions to feed. On another occasion a male western pygmy possum (number 1) was observed actively feeding while it was raining lightly.

Differences between the behaviour of male and female western pygmy possums were observed. Male western pygmy possums tended to be less affected by human presence while radio tracking them and would move and feed as though they were undisturbed. Whereas female western pygmy possums tended to show signs of cautiousness and they would move into the middle of the canopies and venture out occasionally and quickly to feed.

Table 4.3: Distances travelled by the 8 western pygmy possums (*Cercartetus concinnus*) radio tracked between May and September 2007, at sites within the southern wheatbelt region of Western Australia (Distances labelled with * indicate that the distance to the nesting site was not known and not included)

Pygmy Possum Number	Distance Travelled (m)	Nights Tracked	Times Tracked	Hours Tracked
1	116.5 79	05/06/07 06/06/07	9:51pm-1:01am 6:15pm-7:45pm	3 h 10 min 1 h 30 min
2	50 51 30	08/06/07 09/06/07 11/06/07	7:15pm-8:15pm 7:30pm-10:30pm 10:30pm-2:00am	1 h 3 h 3 h 30 min
3	400 0	08/06/07 10/06/07	7:30pm-7:35pm 6:00pm-9:00pm	Distance to nest site from release 3 h
4	85 70	22/05/07 23/05/07	11:40pm-12:20am 9:30pm-10:00pm	40 min 30 min
5	180 0	23/07/07 24/07/07	9:00pm-9:40pm 7:30pm-9:30pm	40 min 2 h
6	443	01/09/07	7:30pm-10:40pm	3 h 10min
7	53*	04/09/07	7:30pm-9:30pm	2 h
8	12*	10/09/07	7:50pm-8:30pm	40 min

Figure 4.2: An aerial photograph showing the habitat utilisation patterns of western pygmy possums (*Cercartetus concinnus*) (numbers 1-3) radio tracked at sites within the southern wheatbelt region of Western Australia.

Figure 4.3: An aerial photograph showing the habitat utilisation patterns of western pygmy possums (*Cercartetus concinnus*) (numbers 4-8) radio tracked at sites within the southern wheatbelt region of Western Australia.

4.2 LOCAL HABITAT CHARACTERISTICS

Based on observations from radio tracking, particular habitat characteristics that seemed important to western pygmy possums became evident. These important habitat characteristics appeared to be the type of vegetation, whether large trees with hollows were in the vicinity, how interconnecting the vegetation canopy was and the amount of flowering trees available. The habitat characteristics that appeared to be important to the western pygmy possum in this study were incorporated in the following categorical vegetation variables measured by CSIRO:

- Vegetation type;
- Vegetation a block or alley;
- Site adjacent to (within10 m) an existing remnant of native vegetation;
- Vegetation life form present at stratum one;
- Intact or interconnecting shrubland/heathland canopy offering nesting and foraging habitat for fauna;
- Presence of large trees;
- Presence of trees with visible hollows (>5 cm diameter) and;
- Plant cover class of trees (from nil to >70% cover).

The vegetation variables listed above and the abundance of western pygmy possums found at sites as recorded by CSIRO were used to determine the significance of habitat characteristics that appeared, through observations in this study to be important to the species. Western pygmy possum abundances and vegetation measurements from the CSIRO data were used rather than data from my study so that comparisons could be made over a range of habitats and not just oil mallee plantations, where a majority of western pygmy possums were captured in this study. Out of a total of 66 captures of western pygmy possums, CSIRO found 37 in oil mallee plantations, 24 in mixed revegetation and 5 in remnant vegetation sites (Table 4.4). For the variable, vegetation type (oil mallee plantation, revegetation or remnant), there was a higher abundance of western pygmy possums at sites of oil mallee and revegetation plantations compared to sites of remnant vegetation (G.L.R analysis: $p = <0.001$). The mean abundance of western pygmy possums at the three different vegetation types was significantly different (KW test: $X^2 = 10.3$; $p = 0.006$) (which rejects the null hypothesis). However, there was no significant difference between the abundance of western pygmy possums at sites of oil mallee plantations compared to sites of revegetation plantations (G.L.R analysis: $p = 0.340$). Western pygmy possums have been shown to be captured more frequently in both oil mallee plantations and mixed revegetation than in remnant vegetation (Figure 4.4).

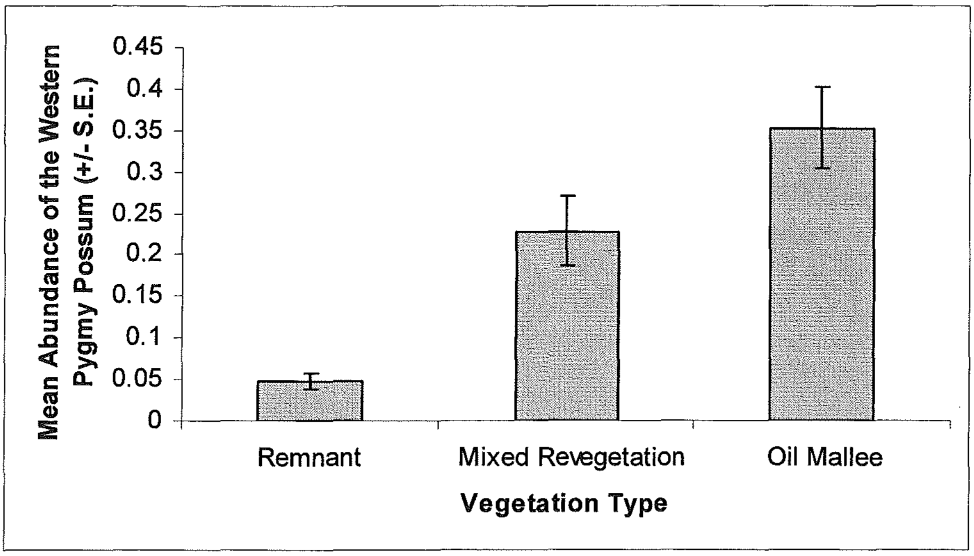

Figure 4.4: The mean (± S.E., *n*= 105 for all 3 sets of data) western pygmy possum abundance at sites of remnant vegetation, mixed revegetation and oil mallee plantations within the southern wheatbelt region of Western Australia as recorded by CSIRO in their Biodiversity Value of Oil Mallee Farming Systems project.

Trapping was undertaken by CSIRO during summer months (Table 4.4). Site 42 in an oil mallee plantation had the largest abundance of western pygmy possums with 8 captures. The next site with a large number of western pygmy possums caught was site 77 within mixed revegetation, with 6 captures. Sites 55 and 78 which were also within mixed revegetation each had a total of 4 captures of western pygmy possums.

Table 4.4: The date and number of western pygmy possums (*Cercartetus concinnus*) caught at study sites for the Biodiversity Value of Oil Mallee Farming Systems project conducted by CSIRO (numbers in brackets indicate that more than one pygmy possum was trapped on that date).

Site Number	Vegetation Type	Number Trapped	Date Trapped
5	Remnant	1	11-Jan-06
7	Mixed Revegetation	2	(2) 15-Feb-07
8	Mixed Revegetation	2	(2) 13-Feb-07
9	Mixed Revegetation	1	15-Feb-07
27	Remnant	1	15-Feb-07
29	Oil Mallees	2	13-Feb-07 15-Feb-07
30	Oil Mallees	2	(2) 13-Feb-07
34	Oil Mallees	2	28-Feb-06 13-Feb-07
35	Oil Mallees	3	11-Jan-06 02-Mar-06 13-Feb-07
36	Oil Mallees	1	28-Feb-06
40	Oil Mallees	2	03-Mar-06 16-Feb-07
41	Oil Mallees	3	01-Mar-06 (2) 15-Feb-07
42	Oil Mallees	8	(3) 28-Feb-06 (2) 01-Mar-06 (2) 13-Feb-07 16-Feb-07
45	Mixed Revegetation	2	23-Feb-06 16-Feb-07
48	Oil Mallees	2	28-Feb-06 01-Mar-06
55	Mixed Revegetation	4	19-Jan-06 20-Jan-06 (2) 30-Mar-07
56	Mixed Revegetation	1	22-Feb-06
57	Mixed Revegetation	1	08-Feb-07
58	Oil Mallees	2	21-Feb-06 23-Feb-06
63	Oil Mallees	1	09-Feb-07
66	Oil Mallees	1	08-Feb-07
68	Remnant	1	08-Feb-07
76	Mixed Revegetation	1	18-Jan-06
77	Mixed Revegetation	6	(2) 21-Jan-06 24-Feb-06 (2) 07-Feb-07 09-Feb-07
78	Mixed Revegetation	4	20-Jan-06 06-Feb-07 (2) 30-Mar-07
79	Remnant	1	21-Feb-06
86	Oil Mallees	1	22-Feb-06
89	Oil Mallees	1	07-Feb-07
90	Oil Mallees	1	09-Feb-07
95	Oil Mallees	1	07-Feb-07
100	Oil Mallees	2	(2) 23-Feb-06
101	Oil Mallees	1	24-Feb-06
102	Oil Mallees	1	09-Feb-07
104	Remnant	1	07-Feb-07

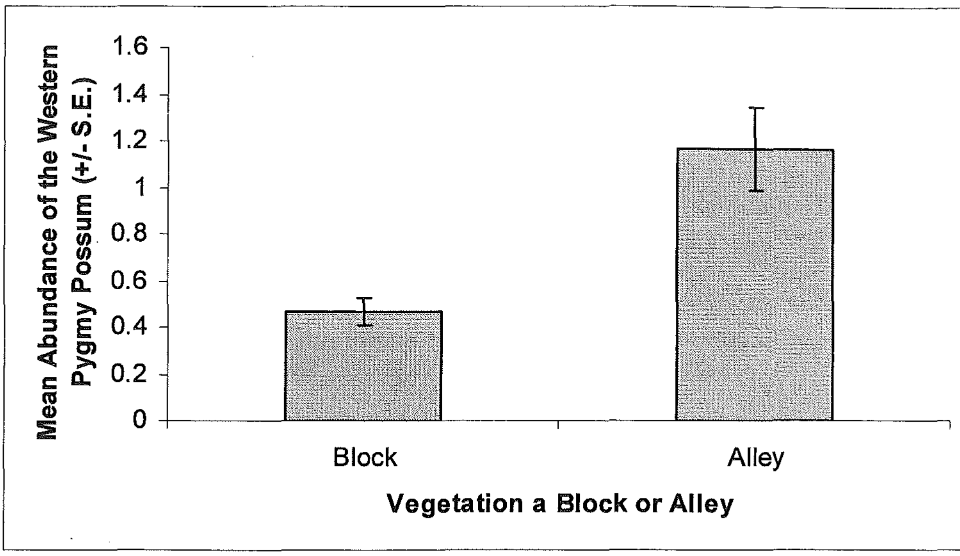

Figure 4.5: The mean (± S.E.) western pygmy possum abundance at sites where vegetation is either in a block (*n*= 81) or alley (*n*= 24) within the southern wheatbelt region of Western Australia as recorded by CSIRO in their Biodiversity Value of Oil Mallee Farming Systems project.

Western pygmy possums were found to be trapped more frequently in oil mallee plantations that were in an alley formation, than in remnant vegetation that was always in a block formation. Therefore the finding that the mean abundance of western pygmy possums was higher where the vegetation was in an alley formation rather than in a block was expected (G.L.R analysis: $p = <0.001$) (Figure 4.5).

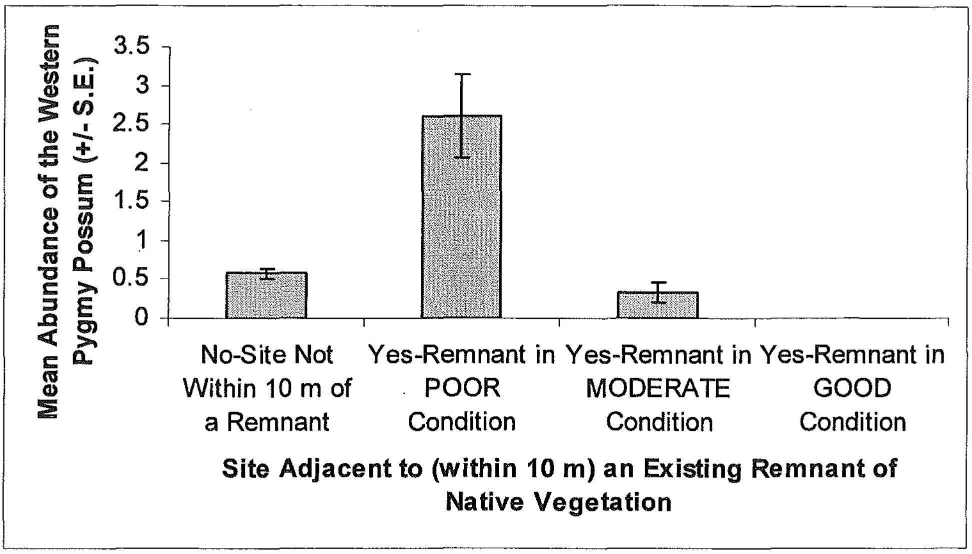

Figure 4.6: The mean (± S.E.) western pygmy possum abundance at sites where the site is not within 10 m of a remnant (*n*= 86), the site is within 10 m of a remnant and the remnant is in poor condition (*n*= 5), the site is within 10 m of a remnant and the remnant is in moderate condition (*n*= 9) or the site is within 10 m of a remnant and the remnant is in good condition (*n*= 2) throughout the southern wheatbelt region of Western Australia as recorded by CSIRO in their Biodiversity Value of Oil Mallee Farming Systems project.

There was a higher abundance of western pygmy possums caught when the sites were within 10 m of a poor quality remnant than sites where there was no nearby remnant or where the nearby remnant was in moderate or good condition (ANOVA: $F = 3.1$; $p = 0.013$) (Figure 4.6). It was observed that western pygmy possums prefer to inhabit farm tree plantations rather than remnant vegetation. However, adjacent remnant vegetation may be important, because western pygmy possums were more abundant where there was an adjacent poor quality remnant than where there wasn't. The abundance of western pygmy possums was then compared between sites with and without nearby (<10 m) remnant, irrespective of condition of remnant (e.g. not within 10 m of remnant compared to within 10 m of a remnant of differing condition). There was no difference found for the abundance of the western pygmy possum between sites with and without remnant nearby (ANOVA: $F = 0.9$; $p = 0.353$).

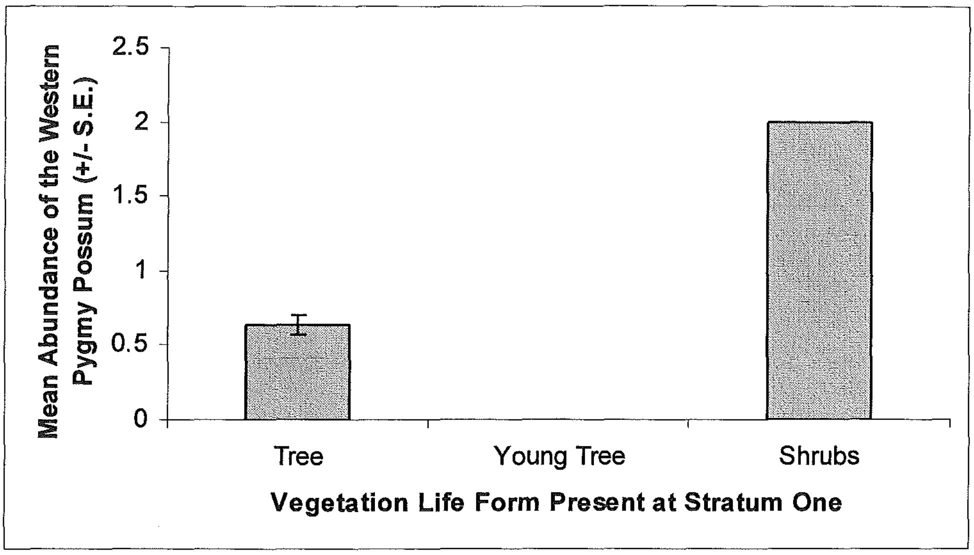

Figure 4.7: The mean (± S.E.) western pygmy possum abundance at different life forms found at stratum one of sites. Life forms of stratum one at sites were either a tree (*n*= 100), young tree (*n*= 4) or shrubs (*n*= 1) throughout the southern wheatbelt region of Western Australia as recorded by CSIRO in their Biodiversity Value of Oil Mallee Farming Systems project.

There was no significant difference between the abundance of western pygmy possums at different life forms of stratum 1 (ANOVA: $F = 1.1$; $p = 0.341$). This finding is unexpected since a higher abundance of western pygmy possums have been found in oil mallee plantations and mixed revegetation sites. Therefore it would be expected that a higher abundance of western pygmy possums would be found at vegetation life forms at stratum 1 to be trees or young trees. Figure 4.7 shows that there is a higher abundance of western pygmy possums where the life form at stratum 1 of sites is shrubs. However, it is important to note that the *n* value for shrubs is only 1. In other words, only 1 site did not have trees as its first strata, and this site had 2 captures.

There is no significant difference between the abundance of western pygmy possums and intact or interconnecting shrubland/heathland canopy offering nesting and foraging habitat for fauna (ANOVA: $F = 0.3$; $p = 0.837$). Radio tracking western pygmy possums revealed that they frequently move through interconnecting canopies to feed on nectar. The species were observed to use connecting canopies where ever possible rather than travelling on the ground. Therefore, it would be expected that sites that had intact or interconnecting shrubland/heathland canopy would have had a higher abundance of western pygmy possums.

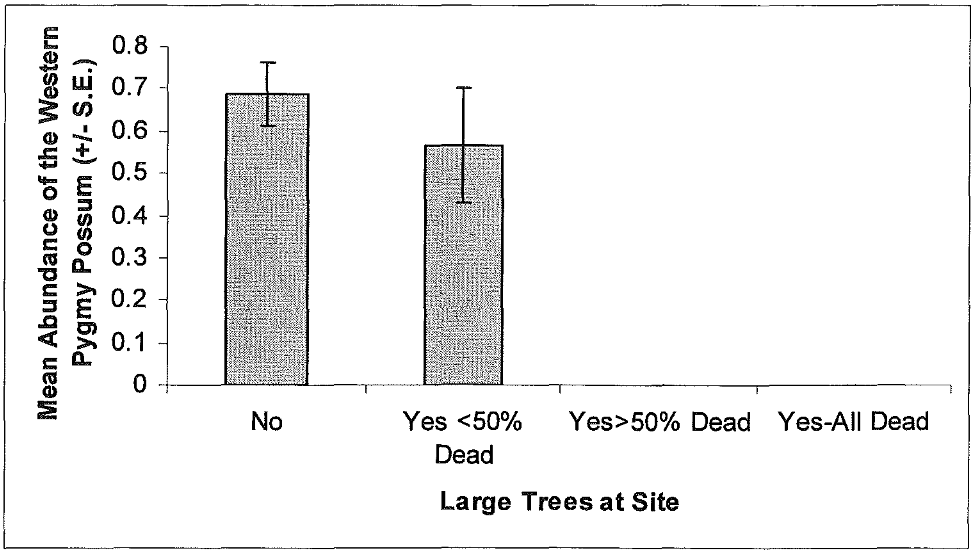

Figure 4.8: The mean (± S.E.) western pygmy possum abundance at sites with no large trees (*n*= 77), sites with large trees with <50% dead (*n*= 23), sites with large trees with >50% dead (*n*= 2) or sites with large trees with all of them dead (*n*= 3) throughout the southern wheatbelt region of Western Australia as recorded by CSIRO in their Biodiversity Value of Oil Mallee Farming Systems project.

The difference between the mean abundance of western pygmy possums at sites with large trees was not found to be significant (ANOVA: F = 0.3; p = 0.833). Western pygmy possums were radio tracked to their nesting sites which were predominately hollows of large trees. It was expected that there would be more western pygmy possums where there were large trees that provided nesting sites. However this may not have been significant because the 50×20 m plot measured at the sites may not have included all the large trees in the area. Figure 4.8 shows that a higher abundance of western pygmy possums were found where there were no large trees and where there were trees that were <50% dead, however this did not prove statistically significant.

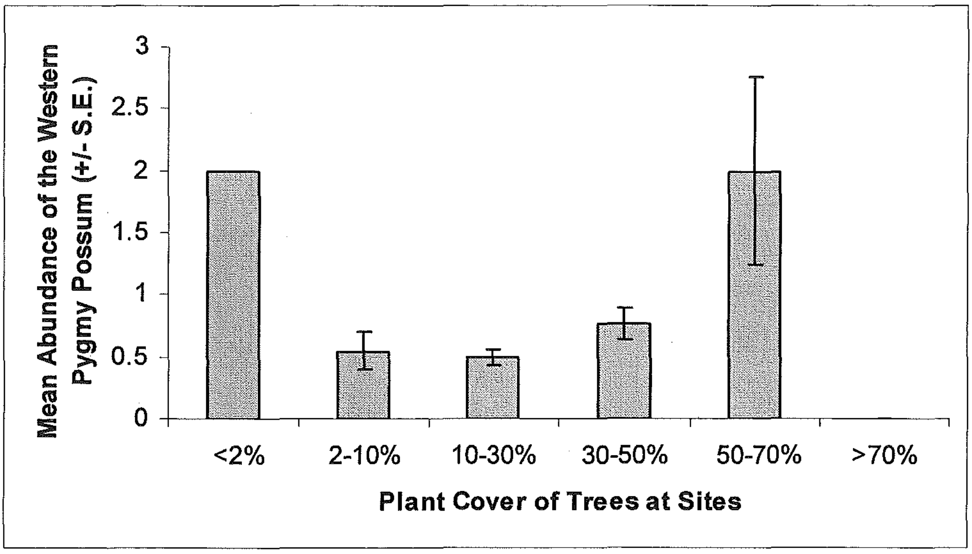

Figure 4.9: The mean (± S.E.) western pygmy possum abundance at sites of different plant cover of trees throughout the southern wheatbelt region of Western Australia as recorded by CSIRO in their Biodiversity Value of Oil Mallee Farming Systems project. The plant cover of trees at the sites ranged from <2% (*n*= 1), 2-10% (*n*= 20), 10-30% (*n*= 61), 30-50% (*n*= 17), 50-70% (*n*= 5) or >70% (*n*= 1).

There was no significant difference between the plant cover of trees at sites and the abundance of the western pygmy possum (ANOVA: $F = 1.7$; $p = 0.139$) (Figure 4.9). There was also no significant difference between the abundance of western pygmy possums and the number of large trees with hollows (G.L.R analysis: $p = 0.081$). This may have been because a higher abundance of western pygmy possums were caught at sites of oil mallee plantations and mixed revegetation that did not have large trees with hollows within the surveyed 50×20 m plot at the site. In fact only one of these sites had a large tree within the plot.

Apart from the habitat characteristics that appeared through observations to be important to the western pygmy possum outlined above; other vegetation variables that were measured by CSIRO demonstrated unexpected significant relationships with the abundance of the species:

- Ground cover litter <1 cm;
- Ground cover of annuals;
- Plant cover of perennial forbs;
- Plant cover of perennial grass, sedges and rushes and;
- Severity and aerial extent of soil erosion associated with site.

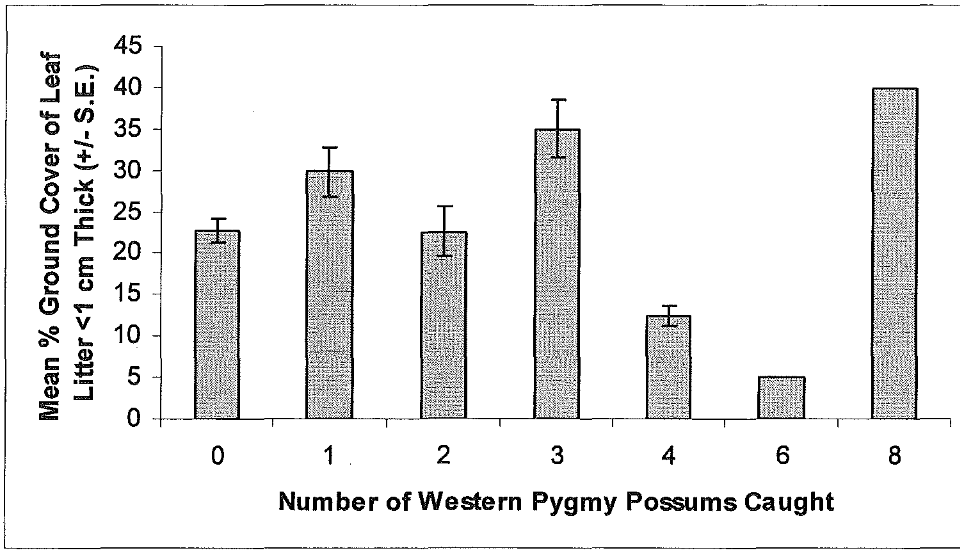

Figure 4.10: The mean (± S.E.) percentage ground cover of leaf litter <1 cm at different sites within the southern wheatbelt region of Western Australia, where western pygmy possums have been caught, as recorded by CSIRO in their Biodiversity Value of Oil Mallee Farming Systems project. Numbers of western pygmy possums caught at the different sites were from 0 (*n*= 71), 1 (*n*= 18), 2 (*n*= 10), 3 (*n*= 2), 4 (*n*= 2), 6 (*n*= 1) to 8 (*n*= 1).

Leaf litter cover (<1cm thick) showed a relationship with the number of western pygmy possums caught (G.L.R analysis: $p = 0.005$). As the percentage of leaf litter increased, the number of the western pygmy possums also increased (Figure 4.10). However, the number of sites where 6 and 8 western pygmy possums were caught was both one.

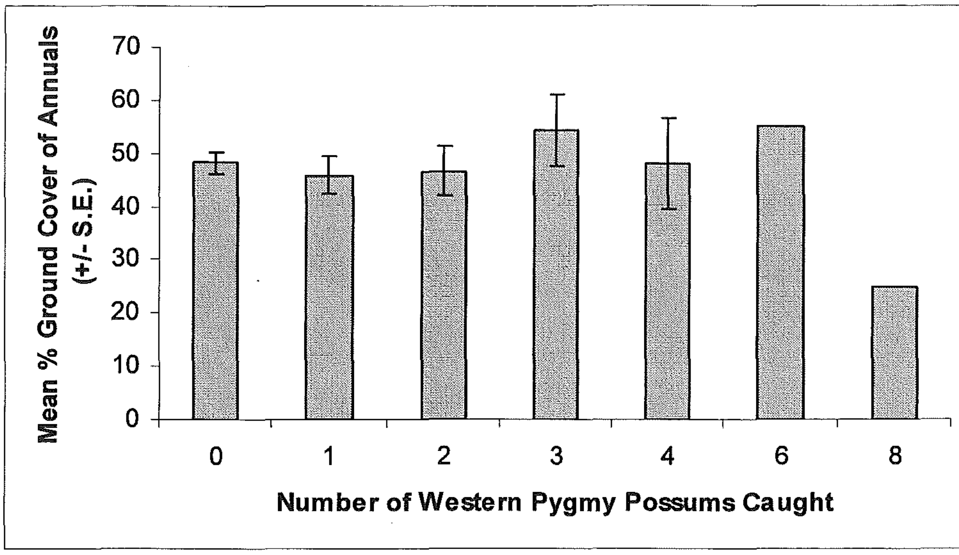

Figure 4.11: The mean (± S.E.) percentage ground cover of annuals at different sites within the southern wheatbelt region of Western Australia, where western pygmy possums have been caught, as recorded by CSIRO in their Biodiversity Value of Oil Mallee Farming Systems project. Numbers of western pygmy possums caught at the different sites were from 0 (*n*= 71), 1 (*n*= 18), 2 (*n*= 10), 3 (*n*= 2), 4 (*n*= 2), 6 (*n*= 1) to 8 (*n*= 1).

As the number of western pygmy possums caught increased the ground cover of annuals decreased (G.L.R analysis: p = 0.023) (Figure 4.11). This may be because western pygmy possums were more abundant at sites of oil mallee plantations and mixed revegetation, which would probably not have as much ground cover of annuals as a remnant site would.

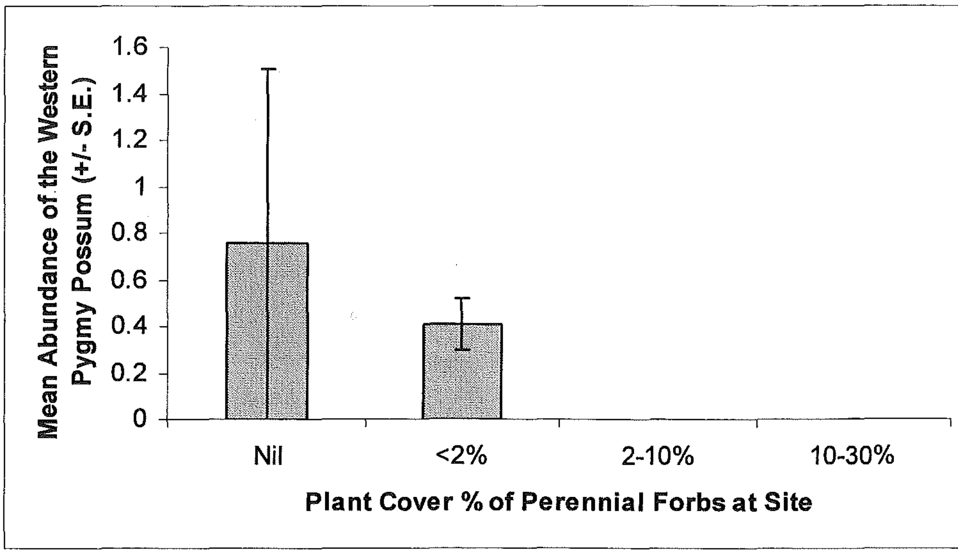

Figure 4.12: The mean (± S.E.) western pygmy possum abundance at sites of different plant cover of perennial forbs throughout the southern wheatbelt region of Western Australia as recorded by CSIRO in their Biodiversity Value of Oil Mallee Farming Systems project. The plant cover of perennial forbs at the sites ranged from nil (*n*= 70), <2% (*n*= 32), 2-10% (*n*= 2) or 10-30% (*n*= 1).

There was a higher abundance of western pygmy possums at sites with no plant cover of perennial forbs (G.L.R analysis: $p = 0.025$) (Figure 4.12). There were also significantly more western pygmy possums at sites where there was no cover of perennial grasses, sedges or rushes (ANOVA: $F = 5.2$; $p = 0.02$). This may be because western pygmy possums are more abundant at sites of oil mallee plantations and mixed revegetation, which would probably not have as much plant cover of perennial forbs or plant cover of perennial grass, sedges or rushes as at sites of remnant vegetation.

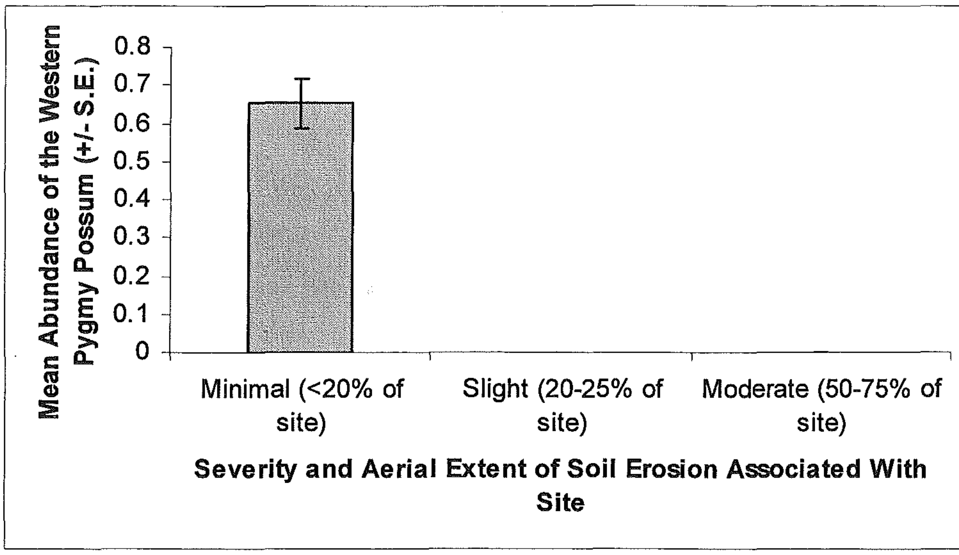

Figure 4.13: The mean (± S.E.) western pygmy possum abundance at sites of different severities and aerial extents of soil erosion throughout the southern wheatbelt region of Western Australia as recorded by CSIRO in their Biodiversity Value of Oil Mallee Farming Systems project. The severity and aerial extent of soil erosion at the sites ranged from minimal (<20% of site) (*n*= 98), slight (20-25% of site) (*n*= 3) to moderate (50-75% of site) (*n*= 2).

The mean abundance of western pygmy possums was higher at sites with minimal (<20% of site) severity and aerial extent of soil erosion associated with the site (G.L.R analysis: $p = 0.016$) (Figure 4.13). This may be associated with the finding that western pygmy possums were more abundant with increasing amounts of leaf litter (<1 cm) at sites, which would generally contribute to a decrease in the amount of soil erosion.

Table 4.5 provides the means (± S.E.) of the local scale vegetation variables measured by CSIRO at oil mallee plantations, mixed revegetation and remnant vegetation sites where western pygmy possums were abundant. Western pygmy possums have shown to be more abundant in both oil mallee plantations and mixed revegetation than in remnant vegetation.

Particular vegetation variables appeared to contribute to the species' response. Western pygmy possums were more abundant where the number of woody perennial stems was higher. The plant cover of stratum one and the plant cover of trees was generally higher in oil mallee plantations and mixed revegetation, where the western pygmy possums were more abundant. Western pygmy possums are often trapped in mallee vegetation areas that can provide adequate cover and abundant nectar (Bennett & Lumsden, 1995; Cadzow & Carthew)

The ground cover percentage of annuals and introduced annuals was higher in oil mallee plantations and mixed revegetation where western pygmy possums were more abundant. The plant cover of annual weeds was also higher where western pygmy possums were more abundant. This may be because farm tree plantation sites where the western pygmy possums were found to be more abundant generally have a higher abundance of introduced annuals than remnant vegetation does.

The vegetation variables; number of large trees, number of large trees with visible hollows and wood with cracks, hollows and/or friable load length had a higher average at sites of remnant vegetation. This result may be because western pygmy possums were more abundant in farm tree plantations that would not have numbers of large trees with visible hollows and high wood load lengths.

Analyses were then undertaken on the oil mallee plantation and mixed revegetation sites without the remnant vegetation sites. This was to determine if there were any differences between various classes of the categorical variables for such replanted farm areas and the mean western pygmy possum abundance. The results showed that there are additional differences in mean western pygmy possum abundance than when all sites are included in the analysis.

Western pygmy possums were found to be more abundant where there was a remnant of poor condition within 10 m of the oil mallee plantation or mixed revegetation site (ANOVA: $F = 3.3$; $p = 0.025$). However, only five of the 72 sites had remnant of poor condition within 10 m, whereas 56 or the 72 sites did not have a remnant within 10 m. When the abundance of western pygmy possums was compared between farm tree plantation sites with and without nearby (<10 m) remnant, irrespective of the condition of the remnant, there was no difference (ANOVA: $F = 0.2$; $p = 0.638$).

There was a significantly higher abundance of western pygmy possums where large trees were present within the site (ANOVA: $F = 8.0$; $p = 0.001$). However, only two out of the 72 farm plantation sites had large trees present. Although this indicates large trees were important at these two sites, large trees may still be present close by to other sites at which trapping occurred.

A higher abundance of western pygmy possums were found at farm tree plantation sites where there were trees with hollows (ANOVA: $F = 15.2$; $p = <0.001$). This result is supported by the observation radio tracking data; that western pygmy possums nest in the hollows of trees. However, only one out of the 72 farm tree plantation sites had trees with hollows. Therefore it seems to indicate that trees with hollows in close proximity to the farm tree plantation sites are important, but it may be that trees with hollows within the larger vicinity of the sites are also just as important.

Sites with coarse woody debris (bark, sticks and branches <10 cm diameter) had a higher abundance of western pygmy possums than sites which didn't (ANOVA: $F = 5.6$; $p = 0.021$). This course woody debris may provide cover and nesting material for the western pygmy possums. Similarly sites with rocks (>10 cm diameter) and/or boulders on the ground had a higher abundance of western pygmy possums than sites with no rocks (ANOVA: $F = 6.6$; $p = 0.013$).

There was no significant difference (ANOVA: $F = 2.2$; $p = 0.095$) in western pygmy possum abundance between cover classes of perennial monocots (grasses, sedges and rushes). However, when sites with and without perennial monocots present were examined, there was significant differences (ANOVA: $F = 6.3$; $p = 0.016$) with more western pygmy possums where such perennial monocots were absent.

T-tests were then used to examine differences between sites of oil mallee plantations and mixed revegetation. A significant difference in the number of local native perennial monocot (grass, sedge and rushes) species was found, with more such species where western pygmy possums were not recorded ($t = -2.6$; $p = 0.012$). Similarly, the plant cover of perennial monocots was higher where western pygmy possums were absent ($t = -3.1$; $p = 0.004$). This may just be because farm tree plantation sites where the western pygmy possums are abundant have less perennial monocots (grasses, sedges and rushes), rather than an actual preference for western pygmy possums to inhabit areas without these perennials.

Another significant finding was that the leaf litter cover (<1 cm) at sites of farm tree plantations where western pygmy possums were present was higher than sites where they were not trapped ($t = 2.1$; $p = 0.037$).

Table 4.5: Mean (± S.E.) of the local scale vegetation variables measured at oil mallee plantations, mixed revegetation and remnant vegetation sites where western pygmy possums (*Cercartetus concinnus*) were caught. Variables were measured for the Biodiversity Value of Oil Mallee Farming Systems project for CSIRO in 2005 (figures in brackets are the number of times the most frequent variable occurs out of the total).

Vegetation Variable	Oil Mallee Plantations	Mixed Revegetation	Remnant Vegetation
Vegetation a block or alley	Alley (14/19)	Block (10/10)	Block (5/5)
Vegetation isolated or adjacent to other vegetation	Isolated (8/19) or adjacent (11/19)	Isolated (7/10)	Adjacent (5/5)
Site adjacent to (within 10m) an existing remnant of native vegetation	No (16/19)	No (7/10)	No (5/5)
Drainage lines depth	0 m	0.23 m (± 0.1)	0 m
Drainage lines width	0 m	1.15 m (± 0.8)	0 m
Large trees	No	No (± 0.1)	Yes <50% dead
Vegetation life form present at stratums 1 to 5 (form: tree, mallee, shrub, perennial herbaceous)	1= Tree (± 0.1)	1= Tree 2= Nil/ Grass/ Shrubs/ Young tree (± 0.5)	1= Tree 2= Nil/Tree (± 0.2)
Height of vegetation at stratums 1 to 5	1= 4.1 m (± 0.3)	1= 7.1 m (± 1.0) 2= 1.01 m (± 0.8)	1= 16.6 m (± 1.3) 2= 2.4 m (± 1.5)
Plant cover of life forms at vegetation stratums 1 to 5	1= 30-50% (± 0.2)	1= 10-30% (± 0.2) 2= Nil or 2-10% (± 0.3)	1= 2-10% (± 0.2) 2= <2% (± 0.6)
Tree health problems (e.g. dieback, insect damage etc)	None affected (± 0.05)	None affected (± 0.2)	Few trees affected (<50%) (± 0.5)
Plant cover trees	10-30% or 30-50% (± 0.2)	10-30% (± 0.2)	2-10% or 10-30% (± 0.2)
Plant cover shrubs	Nil (± 0.3)	<2% (± 0.2)	Nil or <2% (± 0.2)
Plant cover perennial forbs	Nil	Nil (± 0.1)	Nil or <2% (± 0.2)
Plant cover perennial grasses, sedges and rushes	Nil (± 0.1)	Nil or <2% (± 0.2)	<2%
Plant cover local native annuals	Nil (± 0.09)	Nil or <2% (± 0.2)	<2% (± 0.4)
Plant cover annual weeds	30-50% (± 0.3)	50-70% (± 0.3)	2-10% or 10-30% (± 0.4)
Plant cover cryptograms	<2% (± 0.3)	2-10% (± 0.4)	2-10% (± 0.4)
Ground cover soil	15% (± 2.6)	10.4% (± 2.9)	3.8% (±1.6)
Ground cover cryptograms	6.5% (± 2.4)	10.7% (± 4.4)	9.2% (± 3.0)
Ground cover litter <1cm	24.4% (± 4.2)	15.1% (± 4.1)	57.6% (± 9.1)
Ground cover litter >1cm	0%	0.4% (± 0.3)	15.8% (± 9.2)
Ground cover perennials	4% (± 2.0)	1.6% (± 0.2)	1.8% (± 0.2)
Ground cover annuals	47.4% (± 6.4)	61.8% (± 5.7)	12.2% (± 3.8)
Ground cover native annuals	0.1% (± 0.07)	0.2% (± 0.1)	3.2% (± 1.7)
Ground cover introduced annuals	47.3% (± 6.4)	61.6% (± 5.8)	9% (± 2.7)
Bare soil loose or apparently stable	Apparently stable (± 0.1)	Apparently stable (± 0.2)	Loose or apparently stable (± 0.2)
Intact or interconnecting shrubland/heathland canopy offering nesting & foraging habitat for fauna	None (± 0.1)	None (± 0.1)	None

Vegetation Variable	Oil Mallee Plantations	Mixed Revegetation	Remnant Vegetation
No. of large trees (per 50×20 m plot)	Nil	0.5 (± 0.4)	4 (± 0.8)
No. of large trees with visible hollows (>5 cm diameter) (per 50×0 m plot)	Nil	0.1 (± 0.1)	3.6 (± 1.6)
No. of woody perennial stems	160.4 (± 10.0)	58.2 (± 9.1)	71.4 (± 21.8)
Wood load (total length of logs >10 cm diameter) (per 50×20 m plot). <25% with cracks, hollows and/or friable	Nil	0.2 m (± 0.2)	4.6 m (± 2.7)
Wood load (total length of logs >10 cm diameter) (per 50×20 m plot). >25% with cracks, hollows and/or friable	Nil	1.4 m (± 1.2)	55.4 m (± 9.7)
Presence of coarse woody debris (bark, sticks and branches <10 cm diameter)	Nil	<15% of site covered (± 0.2)	<15% of site covered
Presence of rocks (>10 cm diameter) and/or boulders on the ground	Nil (± 0.1)	Nil	Nil or <15% site covered (± 0.4)
Severity and aerial extent of soil erosion associated with site	Minimal (<20% of site) (± 0.05)	Minimal (<20% of site)	Minimal (<20% of site)
Livestock grazing intensity and access to remnant native vegetation and water	Rotationally grazed or Strategically grazed or Never/only historically grazed (± 0.1)	Rotationally grazed or Never/only historically grazed (± 0.2)	Rotationally grazed or Never/only historically grazed or Never/ rarely intentionally grazed (± 0.5)
Fire management regime – intensity and frequency	Site not burnt in past 20+ years	Site not burnt in past 20+ years	Site not burnt in past 20+ years
Floristic composition of weeds present at site	5-10 or >10 weed species present (± 0.2)	5-10 or >10 weed species present (± 0.2)	1-5 or 5-10 weed species present (± 0.2)
Presence of feral animals and livestock on site observed or detected by presence of scats	Sheep, rabbits & horses	Rabbits & sheep	Rabbits & foxes
No. of local native tree species (>4 m) (per 50×20 m plot)	0 (± 0.09)	1 (± 0.2)	3 (± 0.2)
No. of local native shrub species (<4 m) (per 50×20 m plot)	0 (± 0.05)	1 (± 0.3)	2 (± 0.9)
No. of local native perennial grass, sedge and rush species (per 20×20 m plot)	0 (± 0.1)	0 (± 0.2)	4 (± 0.9)
No. of local native perennial forb species (per 20×20 m plot)	0	0 (± 0.2)	2 (± 0.6)
No. of local native annual species (when in season) (per 20×20 m plot)	0 (± 0.1)	0 (± 0.1)	6 (± 1.5)

4.3 LANDSCAPE HABITAT CHARACTERISTICS

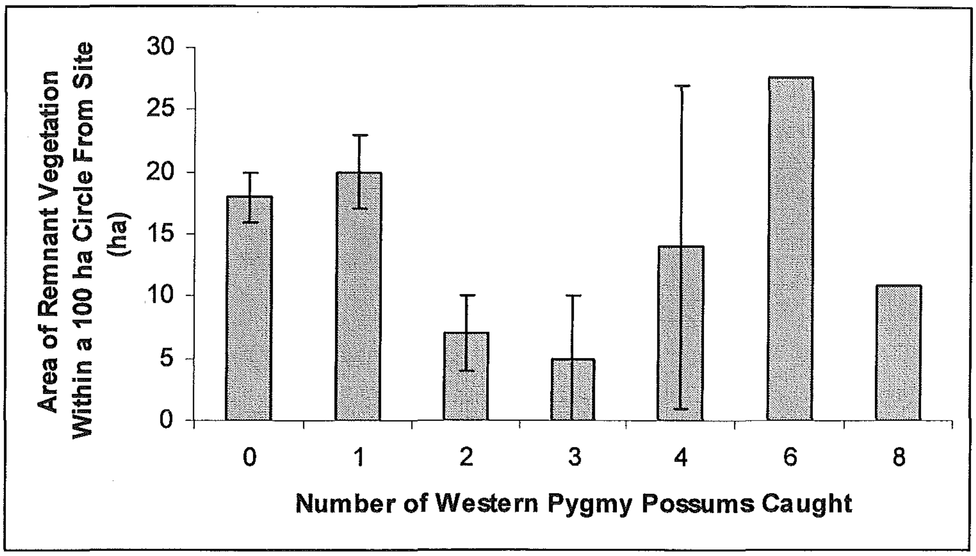

Figure 4.14: The mean (± S.E.) area of remnant vegetation within a 100 ha circle from sites within the southern wheatbelt region of Western Australia, where western pygmy possums have been caught, as recorded by CSIRO in their Biodiversity Value of Oil Mallee Farming Systems project. Numbers of western pygmy possums caught at the different sites were from 0 (*n*= 71), 1 (*n*= 18), 2 (*n*= 10), 3 (*n*= 2), 4 (*n*= 2), 6 (*n*= 1) to 8 (*n*= 1).

There was no significant difference in the abundance of the western pygmy possum at sites that were isolated or adjacent to other vegetation (ANOVA: F = 0.5; p = 0.48). There was also no significant difference in the abundance of western pygmy possums compared to the area of remnant vegetation within 100 ha of sites (ANOVA: F = 2.0; p = 0.072) (Figure 4.14).

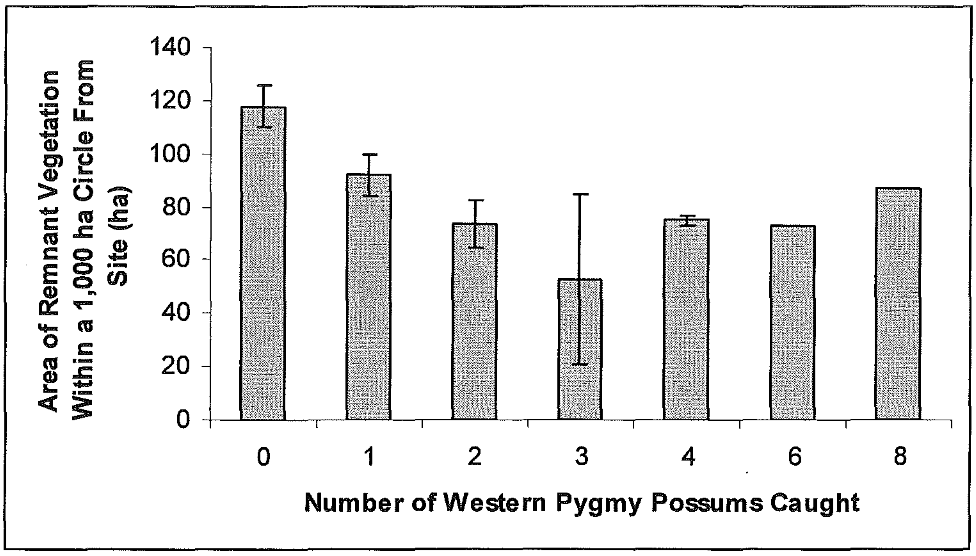

Figure 4.15: The mean (± S.E.) area of remnant vegetation within a 1,000 ha circle from sites within the southern wheatbelt region of Western Australia, where western pygmy possums have been caught, as recorded by CSIRO in their Biodiversity Value of Oil Mallee Farming Systems project. Numbers of western pygmy possums caught at the different sites were from 0 (*n*= 71), 1 (*n*= 18), 2 (*n*= 10), 3 (*n*= 2), 4 (*n*= 2), 6 (*n*= 1) to 8 (*n*= 1).

There was a general negative relationship between the mean (± S.E.) area of remnant vegetation within a 1,000 ha circle from sites and the number of western pygmy possums caught at the sites ($p = 0.016$) (Figure 4.15). However the small number of sites at which numerous western pygmy possums were caught also had relatively high amounts of remnant vegetation remaining within surrounding 1,000 ha, which suggests a possible U-shaped curve (Figure 4.15). The mean area of remnant vegetation within 1,000 ha was significantly greater at sites where western pygmy possums were caught compared to areas in which they were not recorded ($t = -3.4$; $p = 0.01$).

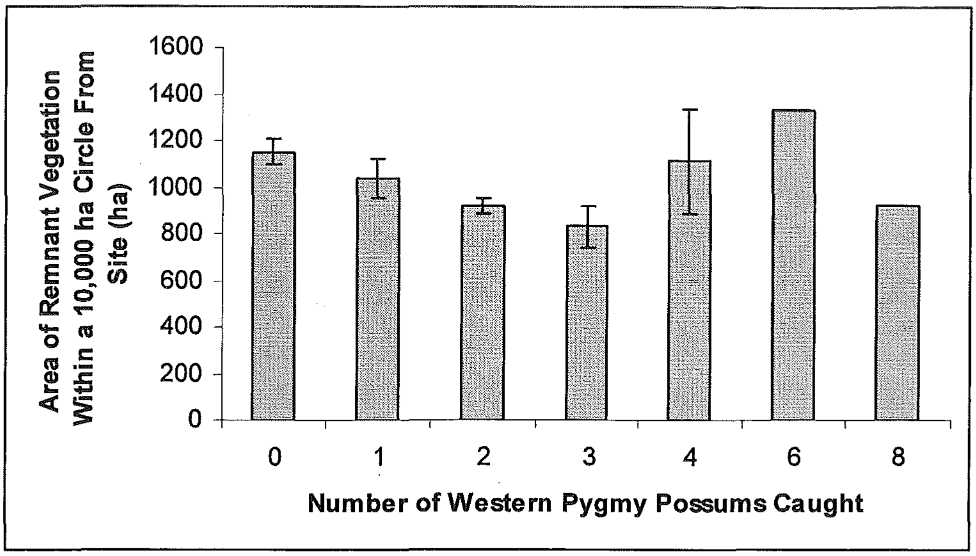

Figure 4.16: The mean (± S.E.) area of remnant vegetation within a 10,000 ha circle from sites within the southern wheatbelt region of Western Australia, where western pygmy possums have been caught, as recorded by CSIRO in their Biodiversity Value of Oil Mallee Farming Systems project. Numbers of western pygmy possums caught at the different sites were from 0 (*n*= 71), 1 (*n*= 18), 2 (*n*= 10), 3 (*n*= 2), 4 (*n*= 2), 6 (*n*= 1) to 8 (*n*= 1).

There was no statistical difference in the number of western pygmy possums trapped and the area of remnant vegetation within 10,000 ha of sites ($p = 0.22$), although mean area clearly decreases with number of western pygmy possums caught up to 3 western pygmy possums, after which the mean area increases (Figure 4.16). Sites where western pygmy possums were captured had less remnant vegetation with the 10,000 ha surrounds than sites where they were absent ($t = -2.5$; $p = 0.016$).

No statistical differences were found for isolated versus adjacent vegetation at a landscape scale, but a trend which suggests that high amounts of remnant vegetation in the landscape matrix is not important to the western pygmy possum was found (null hypothesis rejected).

CHAPTER 5: DISCUSSION

5.1 HABITAT CHARACTERISTICS

The discovery that western pygmy possums found within sites of the southern wheatbelt region of Western Australia were more abundant in oil mallee and mixed revegetation plantations than in remnant vegetation was unexpected. The key to an appropriate management response to the declining status of the Western Australian possum fauna needs to focus on the possums' habitats, principally to identify and secure the best set of the available habitat remnants with high-quality possum habitat values and to control feral animal predation. The identification of habitat patches with a significant possum population is a prerequisite to the subsequent protection of the remnant habitat resource and the possum fauna dependent on it (Bennett *et al*, 2000). Although, this study has revealed that farm tree plantations provide additional food resources; farm tree plantations alone would not be able to sustain western pygmy possums. Therefore, the identification of farm tree plantations as suitable possum habitat and the encouragement to plant these whilst protecting remnant habitats should be the focus to effectively manage the western pygmy possums of Western Australia.

Throughout its range in South Australia the western pygmy possum is often trapped in areas where there is a floristically diverse understorey, particularly where there are plants from the families Proteaceae and Myrtaceae that can provide abundant nectar (Bennett & Lumsden, 1995; Carthew & Cadzow, 2001; Cadzow & Carthew, 2004). It can be abundant, particularly in areas containing mallee species and dry heath (Cadzow & Carthew, 2004; Kemp & Carthew, 2004). In Victoria, the western pygmy possum inhabits the semi-arid mallee areas of the west of the state. The species is considered common or abundant within most of its range, and adequately protected within the large mallee conservation areas of western Victoria (van Der Ree *et al*, 2003). The western pygmy possum is known from only a few locations in far southwestern New South Wales where it was first recognised in 1996. In southern Western Australia the western pygmy possum inhabits mallee heath and dry sclerophyll forests (Smith, 1995). The possibility of the western pygmy possum inhabiting oil mallee and mixed revegetation plantations does not appear to have been studied before, despite the western pygmy possum commonly inhabiting areas of native *Eucalyptus* vegetation within Australia.

Results from a study conducted by Kemp & Carthew (2004) in Newland Head Conservation Park, South Australia found that *C. concinnus* requires a structurally complex habitat that contains many sedges and debris piles, as well as banksias, large *Xanthorrhoea* and eucalypts. Kemp and Carthew (2004) believe that it is important that this diverse habitat structure is conserved for the future persistence of the species. However, *C. concinnus* is also present in areas without a diverse or dense understorey, particularly in drier parts where there are dense clumps of *Triodia* grass rather than shrubs (NSW NPWS, 2001). *C. concinnus* occupies ranges in southern Western Australia where a substantial component of the original range has been subject to extensive land-clearing and this may be why the western pygmy possum has had to find alternative vegetation to inhabit, such as farm tree plantations. There have been few ecological studies conducted on the western pygmy possum and therefore key findings such as the habitat use of farm tree plantations are not known. Studies detailing the habitat requirements of the western pygmy possum throughout Australian need to be undertaken so enable effective management and conservation of the species.

The amount of leaf litter cover (<1 cm) was one local scale vegetation variable which showed a significant trend with the abundance of western pygmy possums. As the amount of leaf litter increased, the abundance of western pygmy possums also increased. Similarly, sites with coarse woody debris (bark, sticks and branches <10 cm diameter) had a higher abundance of western pygmy possums than sites which did not. This may be because during the day western pygmy possums have been observed using nest sites such as leaf-lined nests in tree hollows or leaf clumps on the ground (Smith, 1995; Misso, 1997). The leaf litter may even encourage insects to inhabit the area; which would then provide a food source for the western pygmy possum.

Local scale vegetation variables such as the number of local native perennial monocots (grass, sedge and rushes) species, the ground cover of annuals and plant cover of perennial forbs all decreased with an increase in the abundance of western pygmy possums at the sites. Fragmented animal populations, particularly small fragments in farmland may have higher levels of predation than comparable populations in large continuous habitats (Andren & Angelstam, 1988). Western pygmy possums may prefer lower levels of ground and plant cover in these small vegetation fragments of farm tree plantations so that predators can be seen more easily. For it may also be that the high levels of ground and plant cover is hard for the small marsupial to move through.

At a landscape level, western pygmy possums appeared to have no preference for isolated or adjacent vegetation, but a trend suggesting that high amounts of remnant vegetation in the landscape matrix is not important was found. However, it is possible that remnant vegetation within the landscape is actually important for the species. The monoculture that oil mallee plantations provide would not likely be able to sustain western pygmy possums on their own. For example, the large trees with suitable nesting hollows are not provided in oil mallee plantations. Remnant vegetation in good quality within the landscape may provide a suitable habitat for the western pygmy possum; hence the species do not need to travel outside of the remnants and are not easily trapped. Western pygmy possums were observed to travel considerable distances in short periods of time and a study conducted by Pestell (2005) recaptured one male western pygmy possum 2.5 km away from its original capture site. This finding and the fact that western pygmy possums in this study were only trappable at sites that had flowering vegetation may mean that the species exhibit coincidental switching to different (floral) food items when they are most abundant in the environment, travelling over several hundred metres to other vegetated areas to exploit distant resources.

5.2 MALE & FEMALE CAPTURE RATES

Over the months of May to September there was a total of 39 trapping nights, resulting in 17 captures of the western pygmy possum. A total of 12 males and five females were caught, one of the females was carrying pouch young and one male and one female were juveniles. Of the 17 captures three of the western pygmy possums were recaptures. A study conducted by Pestell (2005) in the Innes National Park, South Australia, also captured male western pygmy possums more often than females. Kemp and Carthew (2004) reported similar trends in male-biased capture of *C. concinnus* in the Newland Head Conservation Park, South Australia. Honey possums (*Tarsipes rostratus*), similar-sized marsupial also exhibit male-biased capture rates (Garavanta *et al*, 2000). This trend was attributed to males being more likely to be caught than females rather than to males being more abundant (Garavanta *et al*, 2000). The male-biased capture rate may simply reflect differences in activity patterns of western pygmy possums, with males being more active than females because of greater home ranges, or the possibility that males were searching opportunistically for mates (Pestell, 2005). This difference in activity patterns between male and female western pygmy possums is supported by the varying distances the pygmy possums travelled whilst radio tracking. The longest distance travelled by a western pygmy possum which included the distance from the nesting site and the distance travelled while feeding was 443 m over 3 h and 10 min by a male. Whereas, the longest travel distance recorded for a female western pygmy possum was 53 m over 2 h; however this did not include the distance to the pygmy possums' nesting site. Therefore the male-biased capture rate may simply reflect that male western pygmy possums are more active and have a greater home range than females.

5.3 SEASONALITY, WEATHER CONDITIONS & CAPTURE SUCCESS

Many mammals show marked differences in capture rates depending on season, for example the honey possum (*Tarsipes rostratus*) and the mountain pygmy possum (*Burramys parvus*). Most seasonal fluctuations are attributed to changes in food availability as well as animal activity (Bos & Carthew, 2001). For example, mountain pygmy possums enter lengthy periods of torpor in winter and are not trappable (Broome, 2001). The decline in capture rates from the summer trapping undertaken by CSIRO to the trapping undertaken in this study during autumn through to spring may be a reflection of cool temperatures inducing torpor in pygmy possums (Ward, 1992). The use of torpor is thought to be opportunistic in the genus *Cercartetus* to overcome periods of low energy levels created by either poor environmental conditions such as low temperatures and/or poor food resources (Geiser & Kortner, 2004). A study of western pygmy possums at Coorong National Park South Australia, determined that individuals entered torpor frequently in autumn, with bouts lasting up to 14 h (Geiser & Kortner, 2004). However, in this study one male western pygmy possum was found curled up clinging to a branch of an oil mallee tree (but not in a state of torpor), while it was raining heavily. This western pygmy possum had moved from its nesting site during unfavourable environmental conditions to feed, but became caught in the rain, where it decided to curl up on a branch of the oil mallee tree rather than travel in the heavy rain. On another occasion a male western pygmy possum was observed feeding while it was lightly raining. It seemed that even when weather conditions were not particularly favourable for the western pygmy possum if flowers providing nectar were abundant, they would take the opportunity to feed rather than retreat into a state of torpor.

5.4 DIETARY HABITS

The dietary habits of pygmy possums are poorly known, especially for most of the *Cercartetus* species. The dental morphology of all burramyids is consistent with them having a component of insects in their diet (Smith, 1986). Of the few studies conducted, it appears that all the pygmy possums are omnivorous, but to different extents. An exact description of the diet from the feeding behaviour of pygmy possums is often not possible due to their small size and nocturnal, often arboreal or cryptic habits, which prevent detailed behavioural observations being made in the field (Tulloch, 2004). A trend with the amount the oil mallee plantations were flowering and the amount of time the western pygmy possums spent in these flowering oil mallees were recorded in this study (Figure 4.1). Therefore the null hypothesis that, western pygmy possums found within the study area do not spend a longer period of time in vegetation that is flowering than in vegetation that is not flowering is rejected. Whilst radio tracking, the western pygmy possums were observed to spend longer periods of time in the oil mallees that were flowering prolifically than in oil mallees with no to a minimal number of flowers. Many flower-visiting animals are selective about the plants they feed on, often displaying a preference for those which provide the greatest energy rewards (Goldingay, 1990; Saffer, 1998). Nectar is an important source of energy for many animals, being a rich, easily digested carbohydrate solution. While nectar is rich in sugars and clearly contributes to an animal's energy requirements, it provides very little in the way of protein. Studies have found that pollen can provide a very effective source of protein in the diet of small mammals. For example, van Tets & Hulbert (1999), found that the maintenance nitrogen requirement of *Cercartetus nanus* was much lower when on a pollen diet than when on an insect diet. The western pygmy possums radio tracked in this study were only ever observed feeding on the flowers of the oil mallee trees. This ability of nectar and pollen to satisfy an animal's dietary requirements provides an explanation for the common occurrence of western pygmy possums in this study to spend longer periods of time in oil mallee trees that were flowering than those that were not.

5.5 FLOWERING VEGETATION REQUIREMENTS

The little pygmy possum (*Cercartetus lepidus*), is highly mobile, most likely as a result of adaptations to spatial heterogeneity of floral resources, i.e. plants with differing flowering times (Ward, 1992). The term drifting home ranges has been applied to mammals that exhibit this behaviour (Read, 1988; Ward, 1992). This term may also be applicable to the western pygmy possum. Over the trapping period, western pygmy possums were only trapped when the vegetation at the sites was flowering. Nectar-feeding, or nectarivory, occurs commonly in invertebrates, but much less in vertebrates (Recher, 1981). Studies on nectarivorous birds have often demonstrated that their abundance activity and nesting are linked to variations in nectar-producing flowers or directly to energy returns from nectar (Armstrong & Pyke, 1991). Law (2001) also found that local abundance of the blossom bat (*Syconycteris australis*) was correlated positively with the density of its main food (nectar). In a species with such a restricted diet as the eastern pygmy possum (*Cercartetus nanus*), shortfalls in floral resources could be serious, as individuals have limited ability to switch over to other foods. Despite this, the diet of the eastern pygmy possum does exhibit coincidental switching to different (floral) food items when they are most abundant in the environment and animals appear to be capable of making movements over several hundred metres to exploit distant resources (Bladon *et al*, 2002). In this study the western pygmy possums were only trappable at sites that had flowering vegetation. A vegetation survey undertaken by CSIRO revealed that a large number of *Eucalyptus* species surrounding the study sites, that would provide a suitable food source for the western pygmy possum, flowered at different times to the oil mallee plantations (Table 5.1). A study undertaken by Pestell (2005), in the Innes National Park, South Australia recaptured one male western pygmy possum 2.5 km away from its original capture site. The maximum distance travelled by a western pygmy possum in this study was 443 m over 3 h and 10 min; indicating that the pygmy possums can travel relatively large distances in a short time span. Therefore the fact that the western pygmy possums in this study could not be caught unless the vegetation at the site was flowering may indicate that the pygmy possums were travelling to the surrounding vegetation that was flowering at the time. Western pygmy possums may only be abundant in oil mallee plantations and mixed revegetation when the vegetation is flowering. The ability to track ephemeral resources appears to be a key component of the success of nectarivores such as the eastern pygmy possum and blossom bat and is likely to be crucial for the western pygmy possum.

Table 5.1: Flowering periods of species of Eucalypts found within vegetation surrounding the oil mallee plantations at sites within the Shires of Narrogin, Wickepin and Cuballing in the wheatbelt region of Western Australia (Source: Department of Environment and Conservation, Retrieved: 05/10/07).

Species	Flowering Period
Eucalyptus eremophila	Aug-Dec
Eucalyptus accedens	Dec-April
Eucalyptus astringens	Sept-Dec
Eucalyptus spathulata	Dec-March
Eucalyptus subangusta	Jan-March
Eucalyptus wandoo	Dec-May
Eucalyptus salmonophloia	Sept-Dec
Eucalyptus phenax	Oct-March
Eucalyptus loxophleba lissophloia	Sept-Feb
Eucalyptus occidentalis	Nov-May
Eucalyptus longicornis	Dec-Feb

In Australia, studies have shown that a relatively large number of non-flying mammals visit flowers (Carthew & Goldingay, 1997). Despite this, we still have only a limited view of the role of these mammals in pollination. Perhaps the most reliable evidence that suggests a role in pollination is that pollen is transferred to the bodies of animals (typically the head and snout) as they feed in a non-destructive way and that animals regularly carry more than trivial loads of pollen (Goldingay, 2000). Throughout this study, western pygmy possums were regularly observed feeding on flowers in a non-destructive way. The western pygmy possum may provide an important ecosystem service to those vegetation species that it feeds on; however, further investigation is required to determine the presence or extent of this service.

5.6 NESTING SITES

Because of the minute size and secretive, mostly nocturnal behaviour of pygmy possums, little is known of their life history and nesting habits in the wild. All the burramyids deposit their young in a nest and suckle them, making them dependent on particular nesting sites at least at certain times of the year (Misso, 1997). Pygmy possums seem to be very flexible in their choice of nesting site and material, a tactic that probably helps them survive in more marginal habitats (Tulloch, 2004). Six of the eight western pygmy possums were radio tracked back to their nesting sites in this study. All six of these pygmy possums were found to use the hollows of *Eucalyptus wandoo* trees as nesting sites. Two of these nesting trees were found amongst roadside vegetation, one was amongst a strip of fenced off remnant vegetation and the other three nesting trees were paddock trees. However, a group of three western pygmy possums (female, male and juvenile) were found nesting in a burrow lined with dried grass below a pitfall trap bucket within an oil mallee plantation, which supports the notion that pygmy possums are flexible in their choice of nesting site and material. A study conducted by Kemp and Carthew (2004), at Newland Head Conservation Park, South Australia found that western pygmy possums found daytime refuge in debris piles, between dead banksia leaf litter, at the base of *Xanthorrhoea semiplana* or *Banskia ornata* plants, in sedges and in the eucalypt canopy. Interestingly in Kemp & Carthew's study (2004), no animals were followed back to tree hollows during the study. Misso (1997) found that hollows were the preferred nesting sites of pygmy possums. The study sites investigated by these authors varied greatly in the number and availability of nest types, particularly in Misso's (1997) study, which took place in a predominately open mallee woodland with sparse understorey. In comparison, the study site in Kemp & Carthew's (2004) study had dense, continuous understorey and few, if any, hollows with an abundance of *Banksia* species.

5.7 THE CONSERVATION VALUE OF PADDOCK TREES

Across Australia, paddock, scattered or isolated trees, broadly refer to the remaining native trees left standing across land that is predominately used for grazing and agriculture. These trees mostly represent the remnants of eucalypt woodlands that have been extensively cleared and modified (Bennett *et al*, 2000). Paddock trees have not been credited with the same conservation value as trees in remnant blocks and have suffered an increasingly negative perception because of this (Reid & Landsberg, 1999). Paddock trees are disappearing at an alarming rate from Australia's agricultural landscapes (Ozolins *et al*, 2001; Gibbons & Boak, 2002) and the consequences of this loss for biodiversity conservation, farm production and landscape aesthetics are not well understood. Results from this study indicate that western pygmy possums in the wheatbelt region of Western Australia that inhabit oil mallee plantations, rely on the hollows of paddock trees as nesting sites. The degree to which these western pygmy possums rely on paddock trees as nesting sites would need to be investigated further; however it seems that paddock trees provide an important habitat for the species. The availability of new hollows in the next century and beyond will be directly influenced by whether successful tree recruitment occurs in farming areas and also assumes that the ecological processes involved in hollow-formation have not been lost (Cutten & Hobber, 2002). Landowners need to be educated on the importance of paddock trees for the conservation of species such as the western pygmy possum; too often paddock trees are cleared because nobody knows of their benefits to biodiversity.

5.8 CONCLUSION

5.8.1 The Value of Farm Tree Plantations

Oil mallee plantations and mixed revegetation in the southern wheatbelt region of Western Australia have been found in this study to provide a suitable feeding habitat for the western pygmy possum. However, these farm tree plantations would not sustain the species out of flowering season. Western pygmy possums seem to be able to travel over several hundred metres to exploit distant resources. Therefore the focus of farm tree plantations for providing suitable habitat to this species is by providing vegetation that is near to remnant vegetation that would provide additional food sources and nesting sites.

Farm tree plantations will have greatest value for wildlife when it is planned and undertaken in a way that meets the requirements of animal species. This study has identified certain values of oil mallee plantations and mixed revegetation that provide a suitable habitat for the western pygmy possum. By incorporating these identified values into revegetated farm areas in the southern wheatbelt region of Western Australia the conservation of western pygmy possums may be enhanced. Values of revegetated farm land for the western pygmy possum were identified as:

- Trees that provide prolific flowers for feeding;
- Large trees with hollows in the vicinity to provide nesting sites; and
- Remnant vegetation within the landscape to provide additional nesting and feeding sites.

It is hoped that this study can improve the low public-profile of the western pygmy possum to ensure continued support for conservation and management initiatives and; recommendations can be given to local farmers on how to manage and/or modify farm tree plantations to enhance their biodiversity value within the landscape.

REFERENCES

Andren, H., & Angelstam, P. (1988). Elevated predation rates as an edge effect in habitat islands: experimental evidence. *Ecology*, 69, 544-547.

Armstrong, D.P. & Paton, D.C. (1990). Methods for measuring amounts of energy available from Banksia inflorescences. *Australian Journal of Ecology*, 15, 291-297.

Armstrong, D.P., & Pyke, G.H. (1991). Seasonal patterns of reproduction in heathland honeyeaters are not responses to changing nectar availability. *The Auk*, 108, 99-107.

Australian Bureau of Statistics (ABS). (2003). *Environmental Statistics Newsletter, ed. 6, January 2003* [online] Retrieved March 22, 2007, from http://abs.gov.au/AUSSTATS/abs

Australian Bureau of Statistics (ABS). (2006). *Western Australian statistical indicators, Sept 2006* [on-line] Retrieved March 22, 2007, from http://abs.gov.au/AUSSTATS/abs@.nsf/featurearticlesbyCatalogue/D6293172EF83F9F7CA25725E001A4B18?OpenDocument

Barrett, G., & Davidson, I. (2000). *Community monitoring of woodland habitats: the birds on farms survey.* In: Hobbs, R.J., Yates, C.J. (2000). Temperate eucalypt woodlands in Australia: biology, conservation, management and restoration. Chipping Norton, NSW: Surrey Beatty & Sons.

Barton, A. (2000). The oil mallee project: A multifaceted industrial ecology case study, Massachusetts institute of technology and Yale university. *Journal of Industrial Ecology.*

Barton, A. (2001). *Oil Mallee Publications* [on-line] Retrieved March 8, 2007, from http://www.chem.murdoch.edu.au/staff/barton/cv.htm#pm

Beard, J.S. (1981). *Vegetation survey of Western Australian Swan, 1:1 000 000 vegetation series. Explanatory notes to sheet 7. The vegetation of the swan area.* Perth: University of Western Australian Press.

Bennett, A.F., & Lumsden, L.F. (1995). Western pygmy-possum, *Cercartetus concinnus.* In: Menkhorst, P.W. (1995). *Mammals of Victoria: Distribution, Ecology and Conservation.* Melbourne: Oxford University Press.

Bennett, A. Kimber, S. & Ryan, P. (2000). *Revegetation and wildlife. What do we know about revegetation and wildlife conservation in Australia.* Report to Environment Australia. Deakin University, Victoria.

Bladon, R. V., Dickman, C.R., & Hume, I. D. (2002). Effects of habitat fragmentation on the demography, movements and social organisation of the eastern pygmy possum (*Cercartetus nanus*) in northern New South Wales. *Wildlife Research*, 29, 105-116.

Bos, D.G., & Carthew, S.M. (2001). Population ecology of *Ningaui yvonneae* (Dayuridae: Marsupialia) in the Middleback Ranges, Eyre Peninsula, South Australia. *Austral Ecology* 27, 103-109.

Bowen, M., & Goldingay, R. (2000). Distribution and status of the eastern pygmy possum *Cercartetus nanus* in New South Wales. *Australian Mammalogy* 21:153-164

Brandenburg, S.A., & Majer, J.D. (1995). A database for revegetated areas in the Tammin region of Western Australia: implications for land owners, managers and researchers. *Nature Conservation: The role of Networks*. 4: 258-270.

Broome, L.D. (2001). Density, home range, seasonal movements and habitat use of the mountain pygmy possum *Burramys parvus* (Marsupialia: Burramyidae) at Mount Blue Cow, Kosciuszko National Park. *Austral Ecology*, 26, 275-292.

Burvil, G.H. (1956). Land clearing control in the eastern wheatbelt. *Journal of the Department of Agriculture W.A.*, 5 (1), 77-79.

Cadzow, B., & Carthew, S.M. (2004). The importance of two species of Banksia in the diet of the western pygmy possum, *Cercartetus concinnus* and the little pygmy possum, *Cercartetus lepidus* in South Australia. In: In: Goldingay, R.L, & Jackson, S.M. (2004). *The biology of Australian possums and gliders*. Chipping Norton, NSW: Surrey Beatty & Sons.

Carthew, S.M., & Cadzoe, B. (2001). *Survey for the western pygmy possum in NSW. Final report for the National Parks and Wildlife Service NSW.* Roseworthy: University of Adelaide.

Carthew, S.M., & Goldingay, R.L. (1997). Non-flying mammals as pollinators. *Trends in Ecology and Evolution* 12, 104-108.

Christensen, P. & Maisey, K.G. (1987). The use of fire as a management tool in fauna conservation reserves. In *Nature conservation: The role of remnants of native vegetation*, 323-329. Ed. By Saunders, D.A., Arnold, G.W., Burbridge, A.A. & Hopkins, A.J.M. Chipping Norton, NSW: Surrey Beaton & Sons Pty. Ltd.

Coates, A. (1987). *Management of native vegetation on farmland in the wheatbelt of Western Australia. Resource management technical report 145.* Western Australia: Department of Agriculture.

Cochran, W.W. (1980). Wildlife telemetry. In: *Wildlife management techniques manual*. Ed. By Schemnitz, S.D. Washington, D.C.: The Wildlife Society.

Cutten, J.L. & Hobber, M.W. (2002). *Scattered tree clearance assessment in south Australia: streamlining, guidelines for assessment and rural industry extension.* Biodiversity assessments section. South Australia: Department for Environment and Heritage.

Department of Environment and Conservation. FloraBase [online]. Retrieved October 05, 2007, from: http://florabase.dec.wa.gov.au/

Friend, J. (1987). Local decline, extinction and recovery: Relevance to mammal populations. In *Nature conservation: The role of remnants of native vegetation*, 53-64. Ed. By Saunders, D.A., Arnold, G.W., Burbridge, A.A. & Hopkins, A.J.M. Chipping Norton, NSW: Surrey Beaton & Sons Pty. Ltd.

Garavanta, C.A.M., Wooller, R.D., & Richardson, K.C. (2000). Movement patterns of honey possums, *Tarsipes rostratus*, in the Fitzgerald River National Park, Western Australia. *Wildlife Research*, 27, 179-183.

Geiser, F., & Kortner, G. (2004). *Thermal biology, energetics and torpor in the possums and gliders*. In: Goldingay, R.L, & Jackson, S.M. (2004). The biology of Australian possums and gliders. Chipping Norton, NSW: Surrey Beatty & Sons.

George, R.J., MacFarlane, D.J. & Speed, R.J. (1995). The consequences of a changing hydrologic environment for native vegetation in southwestern Australia. In *Nature Conservation 4: Role of networks*, 1-684. Ed. Saunders, D.S., Craig, J.L. & Mattiske, E.M. Chipping Norton: Surrey Beatty and Sons.

Gibbons, P., & Boak, M. (2002). The value of paddock trees for regional conservation in an agricultural landscape. *Ecological Management and Restoration*, 2, 205-210.

Gibbons, P., & Lindenmayer, D. B. (2002). *Tree hollows and wildlife conservation in Australia*. Melbourne: CSIRO Publishing.

Goldingay, R.L. (2000). Small dasyurid marsupials – are effective pollinators? *Australian Journal of Zoology*, 48, 597-606.

Goldingay, R.L. (1990). The foraging behaviour of a nectar feeding marsupial, *Petaurus australis*. *Oecologia*, 85, 191-199.

Hamilton, G.J., Hawkins, C., Mlodawski, G. & Wallace, K. (1991). *An evaluation of the remnant vegetation protection scheme 1988-1991.* Western Australia: Department of Agriculture.

Heinjus, D. (1992). *Farm tree planting*. South Australia: Department of Agriculture South Australia.

Heinze, D., Broome, L., & Mansergh, I. (2004). *A review of the ecology and conservation of the mountain pygmy possum Burramys parvus*. In: Goldingay, R.L, & Jackson, S.M. (2004). The biology of Australian possums and gliders. Chipping Norton, NSW: Surrey Beatty & Sons.

Hobbs, R., Catling, P.C., Wombley, J.C., Clayton, M., Atkins, L., & Reid, A. (2003). *Faunal use of bluegum (Eucalyptus globulus) plantations in southwestern Australia. Agroforestry Systems*, 58, 195-212.

Hobbs, R. & Wallace, K. (1991). Remnant vegetation on farms is a valuable resource. *Journal of Agriculture W.A*. 32 (2), 43-45.

Hopper, S.D. (1986). Wheatbelt wildflowers: a rich heritage. *Landscope*, 2 (1).

Horner, B. (1994). The importance of Banksia marginata and Banksia ornata as a food source for *Cercartetus concinnus* (the western pygmy-possum) and *Cercartetus lepidus* (the little pygmy-possum). In: Goldingay, R.L, & Jackson, S.M. (2004). *The biology of Australian possums and gliders*. Chipping Norton, NSW: Surrey Beatty & Sons.

Hume, I.D. (2004). Diets and digestive strategies of possums and gliders. In: Goldingay, R.L, & Jackson, S.M. (2004). *The biology of Australian possums and gliders*. Chipping Norton, NSW: Surrey Beatty & Sons.

Jenkins, S. (1998). *Native vegetation on farms survey 1996 – A survey of farmers attitudes to native vegetation and landcare in the wheatbelt of Western Australia.* National research and development program on rehabilitation, management and conservation of remnant vegetation, research report 3/98.

Kemp,L.F. (2001). *Nest site selection by the western pygmy possum (Cercartetus concinnus) in relation to floristic and structural habitat variables at Newland Head Conservation Park, South Australia,* honours thesis. Adelaide: University of Adelaide.

Kemp, L.F., & Carthew, S.M. (2004). Nest site selection by the western pygmy-possum *Cercartetus concinnus*. In: Goldingay, R.L, & Jackson, S.M. (2004). *The biology of Australian possums and gliders*. Chipping Norton, NSW: Surrey Beatty & Sons.

Kimber, S., Bennett, A. & Ryan, P. (1999). *Revegetation and wildlife. What do we know about revegetation and wildlife conservation in Australia.* Report to Environment Australia. Deakin University, Victoria.

Kortner, G., & Geiser, F. (1995). Effect of photoperiod and ambient temperature on activity patterns and body weight cycles of mountain pygmy-possums, *Burramys parvus* (Marsupialia). *Journal of Zoology* 235: 311-22.

Lamb, D. (1998). Large-scale ecological restoration of degraded tropical lands: the potential role of timber plantations. *Restoration Ecology* 6: 271-279.

Law, B. (2001). The diet of the common blossom bat (*Syconycteris australis*) in upland tropical rainforest and the importance of riparian areas. *Wildlife Research*, 28, 619-626.

Lazenby-Cohen, K.A. (1991). Communal nesting *Antechinus stuartii* (Marsupialia: Dasyuridae). *Australian Journal of Zoology*, 39, 273-283.

Lefroy, E.C., Hobbs, R.J. & Atkins, L.J. (1991). *Revegetation guide to the central wheatbelt, bulletin 4231*. Western Australia: Department of Agriculture Western Australia.

Lefroy, T., Bicknell, D., Hobbs, R., Scheltema, M. & Bartle, J. (1992). *Toward a revegetation strategy for the Western Australian wheatbelt in catchments of green. Proceedings of the national conference on vegetation and water management. Volume A.* Canberra: Greening Australia.

Lindenmayer, D.B., Welsh, A., Donnelly, C.F., & Cunningham, R.B. (1996). Use of nest trees by the mountain brushtail possum *Trichosurus caninus* (Phalangeridae: Marsupialia). II. Characteristics of occupied trees. *Wildlife Research*, 23, 531-545.

McComb,W.C., Anthony, R.G., & McGarigal, K. (1991). Differential vulnerability of small mammals and amphibians to two trap types and two trap baits in pacific northwest forests. *Northwest Science* 65: 109-115.

McFarlane, D.J., George, R.J. & Farrington, P. (1993). Changes in hydrological balance. In *Reintegrating fragmented landscapes: Towards sustainable production and nature conservation*, 146-186. Ed. By Hobbs, R.J., Saunders, D.A. New York: Springer-Verlag.

Menkhorst, P.W., & Knight, F. (2001). *A field guide to the mammals of Australia.* Melbourne: Oxford University Press.

Misso, G.E. (1997). *Nesting sites and habitat of the western pygmy-possum, Cercartetus concinnus.* Unpublished Honours Thesis, University of Adelaide.

National land & water resources audit. (2001). *Australian dryland salinity assessment 2000: Extent, impacts, processes, monitoring and management options.* Canberra: National land and water resources audit.

New South Wales National Parks and Wildlife Service (NSW NPWS). (2001). *Western pygmy possum (Cercartetus concinnus) approved recovery plan.* Hurstville: NSW NPWS.

Norton, D.A. (1998). Indigenous biodiversity conservation and plantation forestry: options for the future. *New Zealand Forestry* 43: 34-39.

Oil Mallee Company (OMC). (2001). *Oil mallee company offer of information statement, July 2001.*

Osborne, M.J., & Christidis, L. (2002). Systematics and biogeography of pygmy possums (Burramyidae: *Cercartetus*). *Australian Journal of Zoology*, 50, 25-37.

Ozolins, A., Brack, C., and Freudenberger, D. (2001). Abundance and decline of isolated trees in the agricultural landscapes of Central New South Wales, Australia. *Pacific Conservation Biology*, 7, 195-203.

Pestell, A.J. (2005). *Patterns of capture, genetic structure and diet of western pygmy possums, Cercartetus concinnus Gould (Marsupialia: Burramyidae), in Innes National Park, South Australia*, honours thesis. South Australia: University of South Australia.

Read, D.G. (1988). Weather and trap response of the Dasyurid Marsupials *Sminthopsis crassicaudata, Planigale gilesi*, and *P. tenuirostris*. *Australian Wildlife Research*, 15, 139-148.

Recher, H.F. (1981). Nectar feeding and its evolution among Australian vertebrates. In *Ecological Biogeography of Australia*. Ed. Keast, A.

Reid, N., & Landsberg, J. (1999). Tree decline in agricultural landscapes: what we stand to lose. In Hobbs, R.J., & Yates, C.J. Eds. *Temperate Eucalypt woodlands in Australia: Biology conservation, management and restoration.*Chipping Norton: Surrey Beatty and Sons.

Rhind, S.G. (2003). Communal nesting in the usually solitary marsupial, *Phascogale tapoatafa*. *Journal of Zoology, London*, 261, 345-351.

Ryan, P. (2000). The use of revegetated areas by vertebrate fauna in Australia. In: Hobbs, R.J., Yates, C.J. (2000). *Temperate eucalypt woodlands in Australia: biology, conservation, management and restoration.* Chipping Norton, NSW: Surrey Beatty & Sons.

Saab, V. (1999). Importance of spatial scale and habitat use by breeding birds in riparian forests: a hierarchical analysis. *Ecological Applications* 9: 135-151.

Saffer, V.M. (1998). *A comparison of foodplant utilisation by nectar-feeding marsupials and birds in the Fitzgerald River National Park, Western Australia.* Ph.D. thesis. Perth: Murdoch University.

Sattler, P., & Creighton, C. (2002). *Australian terrestrial biodiversity assessment 2002.* Australia: National Land and Water Resources Audit.

Schofield, N.J., Ruprecht, J.K. & Loh, I.C. (1988). *The impact of agricultural development on the salinity of surface water resources of south west Western Australia. Water Resource Directorate Report No. WS27.*Leederville: Water Authority of W.A.

Smith, A.P. (1986). Stomach contents of the long tailed pygmy possum *Cercartetus caudatus* (Marsupialia: Burramyidae). *Australian Mammalogy*, 9, 135-137.

Smith, A.P., & Broome, L.S. (1992). The effects of season, sex and habitat on the diet of the mountain pygmy possum (*Burramys parvus*). *Wildlife Research*, 19, 755-768.

Smith, A.P., & Lindenmayer, D.B.. (1988). Tree hollow requirements of Leadbeater's possum and other possums and gliders in timber production ash forests of the Victorian Central Highlands. *Australian Wildlife Research*, 15, 347-362.

Smith, M.J. (1995). Western pygmy-possum, *Cercartetus concinnus*. In: Strahan, R. (1995). *The mammals of Australia.* Chatswood: Reed Books.

Smith, P. (2004). Oil mallees and biodiversity: A win-win for farmers and wildlife? *The Dinkum Oil* 26: 4.

Stapp, P., Young, J.K., vande Woude, S., & van Horne, B. (1994). An evaluation of the pathological effects of fluorescent powder on deer mice (*Peromyscus maniculatus*). *Journal of Mammalogy*, 75, 704-709.

Strahan, R. (1995). *The mammals of Australia.* Sydney: Reed Books.

Tulloch, A. (2004). The importance of food and shelter for habitat use and conservation of the burramyids in Australia. In: Goldingay, R.L, & Jackson, S.M. (2004). *The biology of Australian possums and gliders.* Chipping Norton, NSW: Surrey Beatty & Sons.

Tulloch, A.I. (2006). *The importance of food and shelter for habitat use and conservation of the burramyids in Australia.* Sydney: School of Biological Sciences and Institute of Wildlife Research University of Sydney.

van der Ree, R., Bennett, A.F. & Gilmore, D.G. (2003). Gap crossing by arboreal marsupials: thresholds for use of isolated woodland patches in an agricultural landscape. *Biological Conservation*, 15, 241-249.

van Tets, I.G., & Hulbert, A.J. (1999). A comparison of the nitrogen requirements of the eastern pygmy possum, *Cercartetus nanus*, on a pollen and on a mealworm diet. *Physiological and Biochemical Zoology*, 72, 127-137.

Vernes, K., & Pope, L.C. (2001). Stability of nest range, home range and movement of the northern bettong (*Bettongia tropica*) following moderate-intensity fire in a tropical woodland, north-eastern Queensland. *Wildlife Research*, 28, 141-150.

Wakefield, N.A. (1963). The Australian pygmy possums. *The Victorian Naturalist*, 80, 99-116.

Ward, S.J. (1990). Reproduction in the western pygmy possum, *Cercartetus concinnus* (Marsupilia: Burramyidae), with notes on reproduction of some other small possum species. *Australian Journal of Zoology* 38: 423-438.

Ward, S.J. (1992). Life history of the little pygmy possum, Cercartetus lepidus (Marsupialia: Burramyide) in the Big Desert, Victoria. *Australian Journal of Zoology*, 40, 43-55.

Wheatbelt Development Commission. (2003). *Wheatbelt economic perspective: An update on the economy of Western Australia's wheatbelt region.* Western Australia: Wheatbelt Development Commission.

Wilson, S.M., Whitham, J.A.H., Bhati, U.N., Horvath, D., & Tran, Y.D. (1994). Trees on farms. Survey of trees on Australian farms: 1993-1994. *ABARE Research Report* 95.7.

Wooller, R.D., Richardson, K.C., & Bradley, G.O. (1999). Dietary constraints upon reproduction in an obligate pollen and nectar-feeding marsupial, the honey possum (*Tarsipes rostratus*). *Journal of Zoology, London*, 248, 279-287.

APPENDICES

APPENDIX 1:
Univariate Analyses of Variance (ANOVA) or Non-parametric equivalent – ALL VEGETATION SITES

ANOVA

Vegetation Variable	df	F	Significance
Isolated or Adjacent	1	0.502	0.480
Site adjacent to (within 10 m) an existing remnant of native vegetation of varying conditions	5	3.075	0.013
Site adjacent to (within 10 m) an existing remnant of native vegetation excluding condition	1	0.872	0.353
Large Trees	3	0.289	0.833
Vegetation stratum 1 life form	2	1.087	0.341
Plant cover of trees	5	1.713	0.139
Plant cover of perennial monocots (grasses, sedges, rushes)	3	5.226	0.002
Plant cover of annual weeds	6	1.127	0.353
Plant cover of local native annuals	3	0.310	0.818
Bare soil, loose or stable	2	0.755	0.472
Intact or interconnecting canopy	3	0.282	0.837
Presence of coarse woody debris	2	0.180	0.836
Presence of rocks	2	0.876	0.420
Livestock grazing	5	1.182	0.323
Fire management regime	2	0.508	0.603
Vegetation type	5	2.264	0.054

Kruskal-Wallis Test

Vegetation Variable	Significance
Vegetation oil mallee, revegetation or remnant	0.006

APPENDIX 2:
Univariate Analyses of Variance (ANOVA) or Non-parametric equivalent – MIXED REVEGETATION & OIL MALLEE SITES ONLY

ANOVA

Vegetation Variable	df	F	Significance
Block/Alley	1	1.742	0.191
Isolated/Adjacent	1	0.316	0.576
Vegetation oil mallee, revegetation or remnant	1	0.391	0.534
Site adjacent to (within 10 m) an existing remnant of native vegetation excluding condition	1	0.223	0.638
Site adjacent to (within 10 m) an existing remnant of native vegetation of varying conditions	3	3.310	0.025
Large Trees	1	10.937	0.001
Tree Health Problems	2	1.891	0.159
Plant cover trees	5	0.959	0.449
Plant cover of perennial monocots (grasses, sedges, rushes)	3	2.211	0.095
Plant cover of annual weeds	5	0.922	0.472
Bare soil loose or stable	2	0.574	0.566
Intact or interconnecting canopy	2	0.491	0.614
No. of large trees with hollows	1	15.151	<0.001
No. of large trees	2	7.988	0.001
Presence of coarse woody debris	1	5.574	0.021
Presence of rocks	1	6.554	0.013
Livestock grazing	2	1.057	0.353
Fire management regime	1	0.338	0.563
Floristic composition of weeds	3	0.803	0.496
Presence of feral animals and livestock	7	0.490	0.839

Kruskal-Wallis Test

Vegetation Variable	Significance
Time spent in flowering oil mallees	<0.001

APPENDIX 3:

T-Tests Comparing Means of Sites with and without western pygmy possums- MIXED REVEGETATION & OIL MALLEE SITES ONLY

Vegetation Variable	t	df	Significance
Drainage lines depth	-0.109	54.781	0.913
Drainage lines width	0.359	66.195	0.720
Plant cover-trees	-0.485	57.436	0.630
Plant cover-shrubs	-0.174	48.916	0.863
Plant cover-perennials grass, sedges, rushes	2.991	69.611	0.004
Ground cover %-soil	0.786	68.571	0.435
Ground cover %-cryptograms	0.271	64.301	0.787
Ground cover %-litter <1cm	-2.136	59.950	0.037
Ground cover %-litter >1cm	0.702	53.607	0.485
Ground cover %-perennials	-0.390	38.842	0.699
Ground cover %-annuals	0.957	62.681	0.342
Ground cover %-annuals native	0.742	49.656	0.462
Ground cover %-annuals intro	0.585	64.474	0.560
Number of large trees	-1.223	28.000	0.232
Number of large trees with hollows	-1.000	28.000	0.326
Number of woody perennial stems	-0.082	65.891	0.935
Wood load length with <25% with cracks, hollows	-1.000	28.000	0.326
Wood load length with >25% with cracks, hollows	-0.983	28.856	0.334
Number of local native tree species	0.105	67.990	0.916
Number of local native shrub species	0.194	66.841	0.847
Number of local native perennial grass, sedge	2.586	62.585	0.012
No. of local native perennial forb species	1.243	69.074	0.218
Number of local native annual species	1.702	50.923	0.095

APPENDIX 4:
Generalised Linear Regression Analysis-
ON ALL VEGETATION SITES

Vegetation Variable	p value	+S.E.	Constant
Vegetation (Remnant, mixed revegetation or oil mallee)	Remnant= <0.001 Reveg= <0.001 Oil mallee= <0.001 Reveg= <0.001 Remnant= <0.001 Oil mallee= 0.340	Remnant= 0.441 Reveg= 0.485 Oil mallee= 0.470 Reveg= 0.2 Remnant= 0.2 Oil mallee= 0.2	Remnant Revegetation
Vegetation a block or alley	Block= <0.001 Alley= <0.001	Block= 0.2 Alley= 0.2	Block
Vegetation isolated or adjacent to other vegetation	Isolated= 0.134 Adjacent= 0.370	Isolated= 0.2 Adjacent= 0.3	Isolated
Site adjacent to (within 10m) an existing remnant of native vegetation	No= 0.142 Yes–Remnant in poor condition= <0.001 Yes-Remnant in moderate condition= 0.140 Yes-Remnant in good condition= 0.595	No= 0.149 Yes–Remnant in poor condition= 0.315 Yes-Remnant in moderate condition= 0.6 Yes-Remnant in good condition= 12.2	No
Large trees	No= 0.004 Yes <50% Dead= 0.580 Yes >50% Dead= 0.605 Yes-All Dead= 0.715	No= 0.1 Yes <50% Dead= 0.3 Yes >50% Dead= 12.2 Yes-All Dead= 17.2	No
Vegetation life form present at stratums 1 to 5 (form: tree, mallee, shrub, perennial herbaceous)	Veg Stratum 1: Tree= <0.001 Young Tree= 0.468 Shrubs= 0.113 Veg Stratum 2: None= 0.036 Tree= 0.379 Young Tree= 0.001 Shrubs= 0.065 Grass= 0.045 Herbacious Perennial= 0.560	Veg Stratum 1: Tree= 0.1 Young Tree= 8.6 Shrubs= 0.7 Veg Stratum 2: None= 0.1 Tree= 0.7 Young Tree= 0.4 Shrubs= 0.7 Grass= 1.0 Herbacious Perennial= 12.7	Tree None
Plant cover trees	0.048	0.138	
Plant cover shrubs	0.587	0.132	
Plant cover perennial forbs	0.025	0.344	
Plant cover annual weeds	0.08	0.09	
Ground cover soil	0.272	0.007	
Ground cover cryptograms	0.861	0.01	
Ground cover litter <1cm	0.005	0.006	
Ground cover litter >1cm	0.729	0.08	
Ground cover perennials	0.128	0.03	
Ground cover annuals	0.023	0.004	
Ground cover native annuals	0.609	0.163	

Vegetation Variable	p value	+S.E.	Constant
Ground cover introduced annuals	0.065	0.005	
Bare soil loose or apparently stable	No Bare Soil= 0.070 Loose= 0.107 Apparently Stable= 0.198	No Bare Soil= 1.0 Loose= 1.0 Apparently Stable= 1.0	No bare soil
Intact or interconnecting shrubland/heathland canopy offering nesting & foraging habitat for fauna	0.507	0.3	
Number of large trees (per 50×20 m plot)	0.081	0.09	
Number of large trees with visible hollows (>5 cm diameter) (per 50×0 m plot)	0.081	0.1	
Number of woody perennial stems	0.248	0.002	
Wood load (total length of logs >10 cm diameter) (per 50×20 m plot). <25 % with cracks, hollows and/or friable	0.380	0.06	
Wood load (total length of logs >10 cm diameter) (per 50×20 m plot). >25 % with cracks, hollows and/or friable	0.067	0.009	
Presence of coarse woody debris (bark, sticks and branches <10 cm diameter)	0.442	0.3	
Presence of rocks (>10 cm diameter) and/or boulders on the ground	0.137	0.2	
Severity and aerial extent of soil erosion associated with site	0.016	0.5	
Presence of feral animals and livestock on site observed or detected by presence of scats	0.421	0.04	